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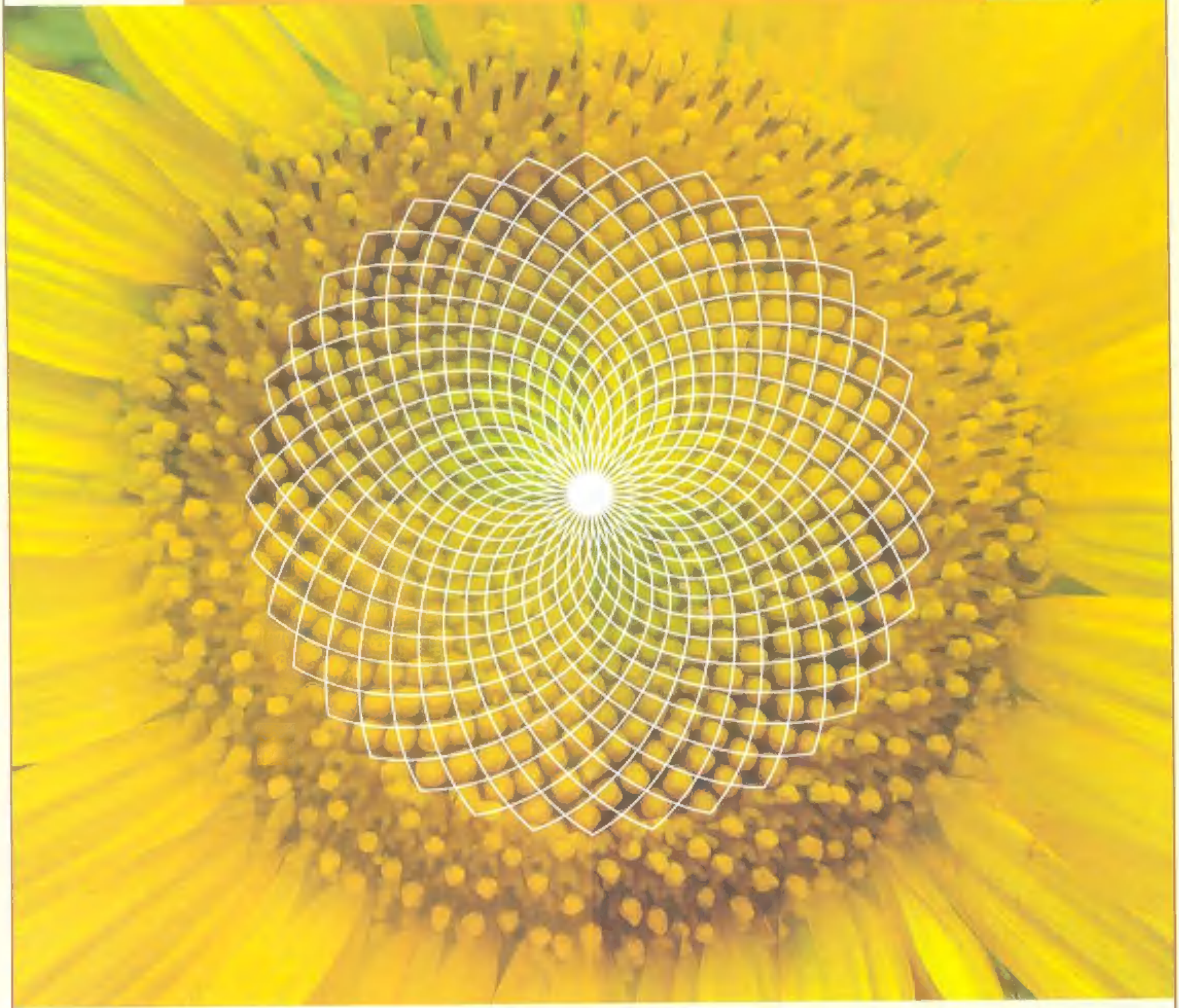

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Editorial

At the outset, I wish our readers – belatedly though – a very happy, productive and fulfilling New Year. For *Propagation*, the year 2012 begins with a change in its editorial board. Dr. Jayanta Sthanapati, former chief editor, has since retired on superannuation after having put the journal on a roll. We express our deep appreciation for his valuable contribution.

In India, we have one of the world's fastest growing networks of science centres, planetariums and other public institutions engaged in science communication. Substantial quantum of professional knowledge and intellectual artifacts in the field are being generated at individual levels, which merits peer attention and recognition. *Propagation* was conceived in this background for sharing and recognizing original works in the field of science communication in India & abroad. And in this venture, we have been receiving valuable support and contributions from both our readers and authors. Thanks to all of you.

This issue has nine articles contributed by professionals in the field of science communication, science historians, practicing scientists and popular science writers.

The article 'Aspects of Iron Technology in India' traces the rich history of iron technology in India at three stages of her techno-cultural development. The authors of the article 'Need for Study of History & Philosophy of Science and Technology' explores why such a study *should become a part of modern S&T education* for inculcating a culture of innovation leading to knowledge societies without gender and culture bias and for a living planet with high sustainability index. 'On Nehru's Concept of Scientific Temper of Mind and its Place in Modern India' the author analyzes Nehru's own idea of scientific temper and gives a short account of its nature and importance in contemporary India.

The article 'Expanding the Role of Educators in Science Museums' addresses the need and scope for widening the role of museum educators in all aspects of their institutional mission and not simply in the organization and conduct of school programs.

Penned on the occasion of the International Year of Chemistry, the article 'Marie Curie - An Immortal Life in Science' is a tribute to one of the greatest scientists of all time about whom Albert Einstein once said, 'Marie Curie is, of all celebrated beings, the only one whom fame has not corrupted.' The author of the article 'Girish Chandra Bose: A Pioneer in Indian Agriculture' gives a brief overview of the pioneering work of Bose in improving Indian agriculture.

Written in a popular manner for non-specialists, the article '100 Years of Superconductivity' traces how our understanding of the phenomenon has developed over the last hundred years. The article 'Social Insects- Shaping Our Future' makes an interesting reading about insects like ants, bees, wasps, which are known for showing complex societal behavior and organizational ability. Recent researches on their behavior have inspired the development of some novel computer programs which promise to solve some of the complicated problems of the modern human society. And the last article in this issue is a scientific paper on the 'Design of an automated system for medical diagnosis'.

We hope our readers will find the content of this first issue of 2012 interesting and useful, and we look forward to their feedback and suggestions.

E Islam
Chief Editor

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Aspects of Iron Technology in India

Vibha Tripathi

Abstract

India had been at the forefronts of iron production right up to the early decades of the twentieth century as corroborated by archaeological, ethnographical and archival material. Recent ^{14}C *dates of the second millennium BCE that are much earlier than dates reported from Afghanistan, neighbouring Iran, and China suggest an indigenous origin of iron in India. Calibrated* ^{14}C *dates of 1800-1500 BCE from Vindhya –Kaimur region of Uttar Pradesh further reinforce an independent origin of iron technology in India. Iron metallurgy appears to have evolved with trial and error, from simple wrought iron with plenty of slag inclusion to steely iron; from small bits and tiny objects to grand structures like the Delhi Iron pillar over the centuries. The wootz steel swords with beautiful watering pattern on the surface became famous all over the ancient world. The history of iron technology in India has been traced here at three stages of techno-cultural development.*

Iron heralded a new era in the history of human civilization. Iron technology has a special place among the ancient technologies that accelerated the pace of progress and brought prosperity in society. In human history Iron Age succeeded Copper-Bronze Age as iron required a different kind of skill and a higher level of metallurgical expertise. The craftsmen who were adept in working with copper and its alloys and other glittering metals like gold, silver etc. that could be used in their native form on a much lower temperature could not smelt iron with the same technique. India has rich iron ore deposit. The ore is not only widely distributed but also easily accessible in the form of nodules scattered on earth's surface. This must have facilitated easy hand picking of rich ore nodules by the early or primitive metal workers. However, richness of mineral and its easy accessibility may not be sufficient conditions for an early and efficient production of metallic iron. The metal workers had to be well conversant with the suitable minerals as well as possess sufficient metallurgical know-how. However, how and under what circumstances the metallurgy of iron evolved has been studied by scholars of other world civilizations. But the history of iron technology in India, its beginning and process of development is yet to be fully studied. Some worthwhile efforts to examine different aspects of iron technology have been made by scholars like, Niyogi (1914), M.N. Banerjee (1927: 432-436; 1932: 364-366), Banerjee 1965; Pleiner (1971:5-36), Sahi 1979: 365-368, 1994; Chakrabarti 1992; Chakrabarti and Lahiri 1994:12-32; Tripathi 1986: 75-79; 1994: 241-251; 2001, 2008; Tewari 2002:99-116, 2003:536-544, 2010: 81-97). On the basis of available information, an attempt is being made to trace a brief history of iron technology in India.

Recent archaeological researches and archival accounts including foreign records by travelers or historians of ancient India, some of them dating back to pre-Christian era bear this out that Indian iron and steel had gained recognition in the ancient world. In 5^{th} century BCE Herodotus, the Greek historian who is also known as father of history stated that in the battle of Thermopylae the Indian soldiers fought with iron-tipped arrowheads (Photius Book VII: 65). Almost at that very time, Ktesias the Greek ambassador to the Persian court and a physician gratefully acknowledged the gift of two swords of Indian steel made to him by the King and the Queen mother (McCrindle 1882, reprint 1973:9). Quintus Curtis reported that the vanquished rulers of North-west India paid a tribute of 100 talents of steel ingots along with bags o f gold dust and other precious items to Alexander. This suggests (1) that iron and steel produced in India at that particular age was considered valuable enough to be presented as a tribute to a monarch. (2) It also suggests that by 6^{th} – 5^{th} century BCE Indian iron and steel had become some kind of status symbol and an object of value being exported to different parts of the ancient world. This assumption gets corroborated by facts like accounts of Arrian (c. 92-175 CE) who mentions about import of Indian steel to Abyssinian ports as early as the beginning of the Common Era. These accounts clearly bear this out that iron metallurgy was sufficiently developed in India at quite an early date. A multi-pronged approach incorporating archaeological, anthropological, metallurgical and literary data is required to study ancient Indian iron technology. We now proceed to look into the genesis and development of iron technology on India.

1. Origin of Iron in India

Whether iron metallurgy was indigenous or was learnt through other sources through diffusion is the key issue of beginning of iron in India. We first propose to discuss the diffusionistic theory of origin of iron in India followed by the alternative view points.

Origin of iron technology in India may be examined by taking into account 1) status of iron at the earliest occupational stratas depicted in archaeological remains and in the literary accounts; 2) chronology of iron on the Indian border-lands to see whether that region had the potential to lend the technological know-how to the neighbouring regions.

1.1 Diffusion of Iron Technology in India

The circumstances and time of introduction of iron has been a much debated issue in Indian archaeology. Gordon (1958) and Wheeler (1958) had ruled out the possibility of use of iron in India prior to 600-500 BCE. It was argued that iron in India was introduced under Achaemenids from the North-western part of the Indian subcontinent around circa 600 BCE. The other set of scholars like Neogi (1914) and M.N. Banerji (1927, 1929, 1932), N.R. Banerjee (1965), Roy (1984) etc. suggested that iron arrived in India through diffusion by the immigrating Aryans (following the disintegration of the Hittite Empire). The Hittites and the Mittannians were known to have possessed the technique of iron production but had secretly guarded this knowledge for centuries. Once the Hittites dispersed to other parts of the world after their defeat in a war with the Mitanni rulers somewhere around 1200 BCE (the date of Hittite movement), the technique of iron working also reached to different parts of the world with them. This assumption gave rise to the theory of diffusion of iron in from a single centre. This also gave rise to association of iron with Aryans. This theory gained further credence by the fact that Rigveda, the earliest text attributed to the Aryans mentions the term *ayas* (that presently stands for iron) several times. Assuming that the Rigvedic Aryans were conversant with iron technology, it was argued that iron was introduced in India by the Rigvedic Aryans who had immigrated through the North-western passes.

The Aryan association of advent of iron in India has been contested by many scholars. Firstly because it is not universally acceptable whether the Rigvedic people came from outside and secondly, whether the word *ayas* that today stands for iron had the same connotation during the Rig Vedic period also. Doubts have been raised on the precise meaning of the word *ayas*. Lallanji Gopal (1961:71-86) closely examined the issue of iron in the Early Vedic period and synthesized the existing evidence on the subject. The word *ayas* in the Rigveda, according to Gopal stood for metal in general, instead of iron as argued by several others like M.N. Banerji (1927, 1929, 1932), N.R. Banerjee (1965), Roy (1984). Lallanji Gopal came to the conclusion that iron was introduced in India during the Later Vedic times. My own examination of the context and usage of the word *ayas* in Rigveda leads to a similar conclusion (for detail see Tripathi 2001:59-65). Even on the ground of metallurgical assessment, the references in Rigveda appear to be applicable more aptly for copper-bronze than iron. During the Later Vedic period (in Vajsaneyi Samhita of Yajur Veda 28.13), the terms *Krishna* or *Shyamaayas* (the black metal) and *lohitayas* (the red metal) denoting iron and copper, respectively were coined (see Tripathi 1994, 1997). It is reasonable to assume thus that Rigvedic *ayas* stood for metal in general and not for iron. With knowledge of iron, a new term had to be coined to describe it during the Later Vedic period. It is also debatable whether the Rigvedic people came from outside to the *sapta sandhava desha* which they refer to as their motherland. Even if we believe that the Rigvedic Aryans were immigrants from outside (from Central Asia or Europe coming through the northwest) there is no definite evidence to suggest that they brought knowledge of iron working with them. In the absence of definite evidence of metallic iron during Rigvedic period, it would be difficult to sustain the argument that the knowledge of iron was acquired from outside by the Aryans of Early Vedic period from the brethren who occupied the distant lands outside the Indian subcontinent.

Additionally, to enquire into the diffusion of iron technology through the north-western borders of India, we need to examine the archaeological evidence of use of iron in the subcontinent through which people and commodities had been finding a passage in India from time immemorial. If the evidence of iron on the border lands is comparatively earlier and strong enough to pass on the technological know-how to adjacent regions than the one found in the mainland India, there is a ground to assume that there was a diffusion of technology from there through these passages.

Archaeologically, the areas adjacent to India are the Iranian borderlands, modern Baluchistan (extending over Indo-Iranian plateau). This region has yielded a large number of cairn burials with iron. Stein (1929) has reported as many as 5100 cairns. Many of these cairns have yielded iron objects along with copper-bronze objects and other cultural material along with pottery. Gordon (1950) suggested Iranian connections of Sialk Cementery B and the cairn burials of Baluchistan on the basis of similarities in pottery, burials and the metal objects. However, Lamberg-Karlovsky and Humphries (1968) disapprove of the 'Sialk B connections' or Indo-European movements to

east' towards the cairn burials of Baluchistan because of lack of 'convincing parallels'. The ecology also plays a role in isolating this area as the 'natural barriers of mountain desert in Baluchistan and southeast Iran have isolated the inhabitants from the domination of any neighbouring power in the 20th century AD.' 'Thus, it seems likely that the occupants of Baluchistan, separated from both east and west, have always maintained a relatively independent existence.' They further state, "The distinctive painted pottery types could not readily be related to the Iranian Plateau or to the painted pottery tradition further to the east. Talking of the possible areas exerting their influence on the Dashtiari and interior Baluchistan, one must look-first to the Persian Gulf trading areas as an outside source of contact. Secondly, there is a connection among the cultures of the northwest India area. The Iranian plateau is an un-distinguished third" (Lamberg-Karlovsky and Humphries, 1968: 269-276).

A close comparison of chronology, typology and pottery traditions of Baluchi cairns and that of North India tends to lend weight to the contention of Lamberg Karlovsky and Humphries (op.cit.). The burden of archaeological evidence does not favour the hypothesis of diffusion of iron into India from the neighbouring West Asian and Central Asian countries. Firstly, a closer examination of tool typology in Iranian and Afghan sites and those in Sindh and Baluchistan area display little common features with iron objects of mainland India. Secondly, the cultural material corroborates the typological study, i.e. the two areas appear to be culturally distinct. Thirdly, the chronological considerations go against any notion of diffusion. On Iran-Afghan sites as well as Indian North-west, iron emerges more or less simultaneously *recent excavations at Charsaddha, however have yielded c. 1200-900 BCE (McDonnel and Conningham 2007: 151-159).* However, it may be noted that recent ^{14}C dates from the middle Ganga Plain sites are much earlier, going back to 1700/1600 BCE (see Table I).This rule out the possibility of iron technology coming through the bordering lands where occurrence of iron is later than this.

The other ground on which the theory of diffusion rests is the inherent complexity of iron metallurgy. Metallurgists like Forbes (1950) strongly advocated diffusionistic origin of iron. By assuming that iron metallurgy is too complex to be developed independently and had to be learnt or acquired under the guidance of specialist iron worker who possessed it. However, recent studies do not subscribe to this view point. Without going into the details of the arguments put forth by recent archaeo-metallurgical researches, it may safely be stated that iron metallurgy is now proved to be a by-product of copper or lead working (for details see Wertime 1980: 13-14, 16; Charles 1980: 151-82 Tylecote 1980: 183-228).

The following points emerge from the foregoing discussion:

1. An uninterrupted use of iron starts only around 1100-1000 BCE on Indo-Iranian borderlands, that too very sparingly in the graves of a selected few.
2. In the neighbouring regions of the Indian borders, none of the areas appear to be in a position to pass on knowledge of iron metallurgy to India. Chronologically or typologically these regions are distinct and disparate.
3. The Rigvedic society does not seem to possess iron technology, therefore even if they had interactions or relationship with the Avestan or other brethren on the so called Aryan trail, this cannot be taken to be a source of iron technology in India.
4. In Kashmir Valley at Gufkral and in Charsadda there are early ^{14}C dates. But so far no concrete evidence of intrusions has been found in these areas. These were at best early centres of iron production. The earlier phase of megalithic cultural deposit does not have iron. It was evolved in the succeeding phase. Foe all we know today, iron is much earlier at Kashmir Valley and may have passed it to the adjacent regions.
5. The assumption that iron metallurgy had to be learnt from those who had already mastered it is no longer tenable. It is well established now that metallic iron was a by-product of copper or lead working. Therefore, the idea that no independent beginning of iron is possible does not hold good at present state of our knowledge.

On the basis of the foregoing, it may safely be argued that iron in the Indian subcontinent was not an outcome of outside contacts. Therefore, let us explore the prospects of an indigenous origin of iron in India.

1.2. Indigenous Origin of Iron in India

As an alternative view point, let us examine the indigenous theory of beginning of iron in India The circumstances and the chronological framework of occurrence of iron in India needs to be evaluated here.

A. Accidental Production of Iron

Could metallic iron be produced incidentally? Do we have such evidence in archaeological records? Let us examine the archaeological evidence with this angle. A new fact emerged by a close look at the excavated material of Ahar, Rajasthan. Sahi (1979:365-368) noticed presence of iron objects in a horizon labeled as Chalcolithic by the excavators. These objects were present in a mid-phase of the Chalcolothic culture that was dated by the excavators between 16th to 13th centuries BCE. These objects could be a product of

smelting of chalcopyrite ore being smelted by the Chalcolithic metal workers at Ahar. (Tripathi 1986:75-79). Attention may also be drawn to the very interesting piece of evidence from Noh, District Bharatpur in Rajasthan which yields tiny bits of iron in a Black and Red Ware (BRW) context in pre-PGW period. A regular use of iron starts at the site from the earliest level of the succeeding PGW period. It is possible to deduce from the evidence that some kind of accidental discovery of iron was made at Noh by early metal workers. Could Iron be accidentally produced at Ahar or Noh, during copper working? What must have followed as a natural corollary was a recognition of iron as a metal in its own right and its deliberate production subsequently.

B. Chronological Evidence of Early Iron Production

Early radiometric dates from a large number of sites in the Vindhya-Ganga plain away from the borderlands of India have added new dimension to emergence of iron in India (see Table1). Sites in the eastern parts of the Vindhyas like, Raja Nal-Ka-Tila and Malhar near Varanasi have yielded ^{14}C dates going back to the 2nd millennium BCE (Tewari 2003, Table III.2 & III.3; 2010: Tables 1-4: 81-97). Dadupur in Lucknow, Jhusi near Allahabad and Aktha in Varanasi have also yielded early dates from iron bearing layers. The iron objects coming from Raja Nal-Ka-Tila are of different types. These are: a nail, an arrowhead, a knife and a chisel. Radiocarbon dates from this iron bearing period range between 1400-800 BCE. Nearby, there is the site of Malhar on river Karamnasa, a tributary of Ganga. Malhar is situated in the hematite rich zone of the eastern Vindhyas. Period I of the site is iron free. Period II succeeds the preceding period without any break in culture. Iron appears during the period II. The iron artifacts are nail, spearhead, arrowhead, awl, knife, bangle, sickle and ploughshare (Tewari 2003, Fig. 4). Slag and tuyeres were also found in abundance at the site and in the nearby ore-rich area. One may easily conclude, seeing the massiveness of the slag heaps and other associated remains that it was an iron production centre. The activity seems to have continued unabated for centuries. Till recently this region had been occupied by the Agaria community showing evidence of pre-industrial working and a possible survival of traditional Indian iron technology in the region. The ^{14}C dates from the iron bearing period II are 1993 cal. BC (3390 ± 160 BP), (3430 ± 90 BP), 1679-1442 cal. BC. At Dadupur, iron has been reported right from the earliest cultural deposit of period I. The strata have been ^{14}C dated between 1900-1700 BCE. The iron objects like arrowheads found in this period are in a highly corroded state. Likewise, there are two ^{14}C dates from Aktha (Varanasi) going back to 17th century BCE (Table-1). In the nearby area early ^{14}C dates of 1107-844 BCE have recently been reported from the site of Jhusi at the confluence of Ganga and Yamuna in Allahabad. Lahuradeva in district Sant Kabir Nagar (Basti) has yielded iron in period III dated to 1300-1200 BCE. Outside contacts with this region are indeed a remote possibility as this is a land locked area in the heartland of India in the Vindhya-Ganga Plain.

Another context in which we come across an early evidence of iron are megalithic burials. Megaliths have been found from Kashmir in the North to the peninsular India in the South. But maximum concentration of megaliths has been noted in the southern part of India. At Gufkral in Kashmir, as noted above, iron has been reported from the megalithic phase II. The phase I of megalith is iron free dated by ^{14}C determinations to 3790±110 and 3570±100 BP. The excavator Sharma (1992: 67) proposes a date of 1550-1300 BCE for the iron bearing deposit. The ^{14}C dates for the period are c 1888- 1674 cal BC. In Deccan and south India iron first appears with the megalithic culture. At the settlement site of megalithic culture at Takalghat (Deo 1982) iron appears in the earliest levels, with a few indeterminate objects but its use becomes more common in the subsequent levels. The typology of these megalithic burials shows a distinct character. It had been dated to 750 BCE by Deo on the basis of the cultural material as was assignable to such remains during that period. However, the recent ^{14}C dates of 1400 BCE from Vidarbha region of Maharashtra are 2940±160 BP, 3080±120 BP and 2820±100 BP (Tewari 2003, table 1). The calibrated dates will fall in the range of 1393 to 834 BCE which is much earlier than the date suggested by Deo. These dates push back the antiquity of iron bearing levels in Vidarbh region to 1300 BCE. The recent analysis of iron objects from Mahurjhari show knowledge of steel making in this region in ninth century BCE (Deshpande 2010: 636-639). This could have been achieved only with a long experience in iron metallurgy. There are ^{14}C and AMS dates from sites like Hallur (11/1200 BCE), TL dates Tadkanhalli and Komaranhalli etc. that take back the antiquity of iron in peninsular India to1400 BCE. Thus we come across radiocarbon dates ranging from first half to middle of the second millennium BCE from several parts of the Indian subcontinent.

On the basis of such early chronology of use of iron in India, it may safely be argued that iron technology in India had a much earlier beginning than in the neighbouring countries. These early dates therefore point at an earlier and thus independent and indigenous

origin of iron in India. If it was discovered by early metal workers who experimented and subsequently perfected the metallurgy, this must have been a gradual process. Whether it is discerniable in iron tool typology brought forth in excavations needs to be looked into at this stage.

II. Stages of Iron Technology

As the archaeological data suggest there was an evolutionary trend in iron metallurgy. We find a development in metallurgy from simple wrought iron to steely iron. The number and quality of iron objects shows improvement over the period that actually spans over thousands of years. Therefore the Iron Age should be studied accordingly. Here the Age of Iron has been classified under three stages, namely, Early, Middle and Late Iron Age.

II.1. Early Iron Age (From the earliest times to 700/600 BCE)

We have hardly come across ornamental or bi-metallic objects of iron as reported from several Old World sites. Nor there are clear-cut evidences to demonstrate experimental stages in iron metallurgy. However, we may cite the case of Noh. There is indeterminate tiny

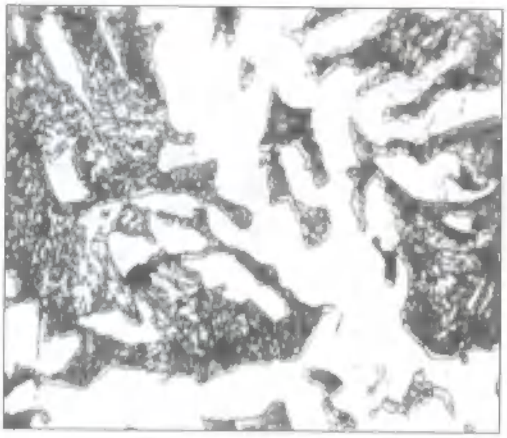

Plate 1a: Photomicrograph of iron implement showing Widmanstatten pattern, Hatigara, West Bengal, India.

piece of iron at a period dominated by Black-and-Red Ware (BRW) though a regular use of iron starts from the succeeding Painted Grey Ware (PGW) period at Noh. Earlier, the PGW culture was supposed to be the first iron using culture (Tripathi, 1976) but in recent decades there are several sites like Noh and Jodhpura (Rajasthan), Jakhera, (district Etah), Abhaipur (district Pilibhit), Dadupur (district Lucknow, Uttar Pradesh) which have yielded iron in a pre-PGW

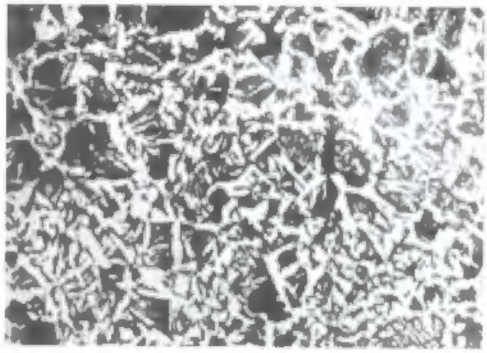

Plate 1b: Photomicrograph of iron implement showing carburization, Hatigara, West Bengal, 500x.

context. The associated potteries are BRW and Red Ware. Jakhera has notably yielded an indeterminate object and an arrowhead with a long tang from the Pre-PGW period from its BRW pottery using cultural period assigned by the excavator to middle of the second millennium BCE. From the succeeding Period III.A (Proto-PGW period) 19 iron objects like hoe, sickle, and arrowheads along with lump and slag were found. A furnace base was also recovered from the proto-PGW phase at Jakhera indicating local smelting of iron (Sahi 1994: 144). From Period III B - the Painted Grey Ware period - hoe, sickle, spearhead, arrow-head, dagger, chopper, chisel, axe, nails, rods etc have been reported. (Sahi 1994: 142, Figs. 14, 15). But generally other sites in the region yield iron from the PGW period. The site of Atranjikhera, situated nearby has no iron in its pre-PGW period. Iron appears there for the first time from the PGW period. The 2.50m thick PGW deposit divided into three sub-periods yields iron from the earliest strata. The lowermost phase has yielded only seven indeterminate bits and some lumps of iron; regular tools appear from mid-PGW phase (46 objects); and the upper phase yields 81 objects (Gaur 1983; see Plate 2a). This indicates a gradual but consistent rise in iron objects between BCE 1100/1000 and 600. Significantly enough, all these sites mentioned above, are located near the Agra-Gwalior iron ore deposit.

As we move further east in the Ganga plain, there are several early Iron Age sites such as Chirand, Sonpur, Panr etc. in Bihar and Hatigra, Pandu-Rajar-Dhibi, Mangalkot etc. in Bengal (see Tripathi 2001). The latter has yielded iron objects from the earliest phases of occupation with 8 objects, like arrow-head, spearhead, nail and rod besides the 8 indeterminate pieces. A furnace along with 16 iron objects was found in a trench of 6x6 m. at Mangalkot from the lowest

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Plate 1c: Electron photomicrograph of iron implements, Hatigara, West Bengal, 3000x.

level datable to 1200 BCE. The succeeding period has yielded more evolved shapes like sickle, chisel, peg, and a knife or sickle blade (?) from mid-phase of the culture (Datta 1992: 293-308).

By and large, the metallurgy of iron at this stage was quite elementary. Bloomery iron that could be produced at much lower temperature was the norm, slag inclusions are found in the matrix of iron (see Plate 2a showing composition of a celt from Tadkanhalli).

Plate 2a: Microstructure of a celt, Tadkanhalli, India.

Plate 2b: Iron objects from PGW level, Atranjikhera, Uttar Pradesh, India.

A dagger dated to 1100-1000 BCE was analysed from Hatigra (Ghosh and Chattopadhyay 1987: 21-27; see Plate 1a, b and c) had widmanstatten structure due to prolonged exposure at a temperature of about 1200°C followed by a slow cooling. It is said to be a 'low carbon hypoeutectoid steel'. The above mentioned specimen shows carbon indicating carburization (see Plate 1b). Objects from Pandurajar Dhibi and Mangalkot have a high percentage of silica in them (De and Chattopadhyay 1989; Datta 1992: 303). It shows the elementary nature of metallurgy and low efficiency furnaces in use at this stage. But samples analysed from the megalithic site of Mahurjhari in Deccan as noted earlier, shows steeling (Despande 2010). This may indicate existence of regional centres that experimented with metallurgy and developed the technology of crucible steel that later comes to be known as crucible steel or wootz steel.

II.2. Middle Iron Age (8th - 7th Century BCE to 1st to 2nd AD)

The Northern Black Polished Ware (NBPW) succeeds PGW culture in North India in *circa* 800/700 BCE. It is contemporaneous with late phase of Painted Grey Ware culture as the two cultures overlap at most of the sites. This was a period of consolidation of iron technology with traces of steeling, case hardening and

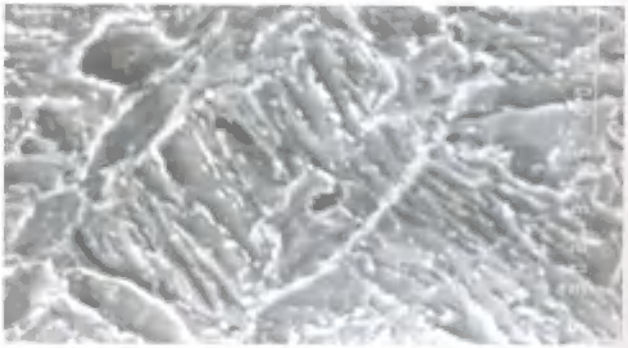

Plate 3a: Electron photomicrograph of Sickle showing tempered martensitic structure, Pandurajardhbi, West Bengal, 3000x.

Plate 3b: Iron objects, Agiabir, Uttar Pradesh, India (No.8 from Stage III).

carburization. A relative increase is recorded in the number and types of iron objects (Table 2). There is a qualitative and quantitative improvement in iron objects (see Plate 3b, iron objects from Agiabir). We come across more sophisticated weapons like javelins, lances, daggers, blades, elephant goads, which occur together with the earlier types that become more prolific. Agricultural implements rarely reported from Early Iron Age, with a few exceptions like the site of Jakhera yielding iron sickle and ploughshare became relatively frequent during this period.

Six iron samples from Rajghat (Varanasi) belonging to 600-400 BCE were analysed. All of them are found to be of wrought iron having slag inclusion. Evidence of carburization has been attested in sample No. 6 at Rajghat. It has 1.10% carbon. However, it is difficult to ascertain whether carburization was deliberate (Bharadwaj 1979:148).

An iron sickle of Pandurajar Dhibi (Period III, NBPW phase) shows the presence of martensite and a non-uniform structure. It also exhibits retained acicularity at certain places, especially around large patches of ferrite areas. Electron micrographs obtained at a magnification of 1000x and 3000x clearly represent its tempered martensitic structure (Chattopadhyay 2004: 98 plates 51, 52; see Plate 3a). It may be said that the iron of the sickle blade had been forged at a significantly high temperature to extricate the slag particles giving the metal a more homogenized structure. Carburization was done during manufacturing of the tool by subsequent heating and forging. Inside the core, the carbon content that is retained is only 0.22%. But the high level of corrosion that took place over the time must have caused depletion of carbon. There is also an uneven distribution of carbon concentration. It indicates that carbon was more than 0.4% initially.' There are also indications of quenching and tempering (De and Chattopdhyay, 1989: 37).

II.3. Late Iron Age (2nd AD to 5th - 6th Century AD)

In the opening centuries of Christian era there is not only a proliferation in tool types (Table 2), but iron metallurgy seem to improve significantly. The iron objects from the site of Khairadih, district Ballia in Uttar Pradesh show a rich variety and good skill of the artisans (see Fig. 1b). Techniques like lamination and quenching are evidenced (Plate 4a, bent knife from Sringaverpur, Uttar Pradesh). In 200 A.D. Taxila has yielded rich iron tool repertoire, including some armour grade weapons (see Fig. 1.a). Hadfield (1913-14) found many of these to be high carbon steel that compares closely with iron production by ethnic smelters. Sisupalgarh in Odisha (datable to 5th-6th A.D., Lal1949: 95, Fig.10.32) yielded a caltrop, a weapon to be used in the battlefield. It is well attested that ancient Indian smiths at this stage had a thorough knowledge of the importance of carbon alloying, case hardening and tempering. However, these techniques seem to have been used judiciously wherever necessary. For

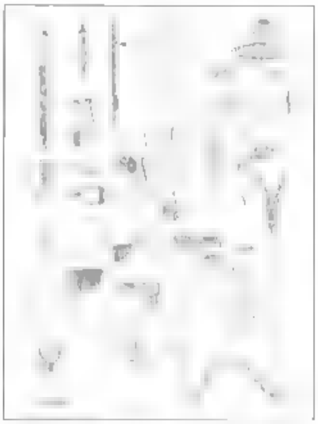
Fig. 1a: Iron objects, Stage III, Taxila, Pakistan.

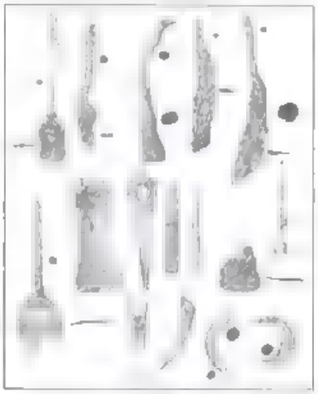
Fig. 1b. Iron objects, Stage III, Khairadih, Uttar Pradesh, India.

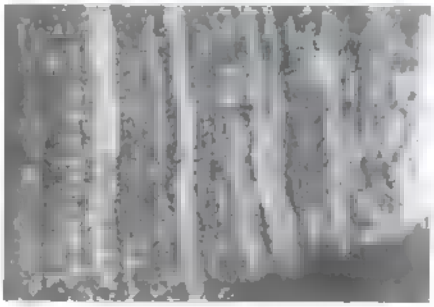
Plate 4a: Microstructure of a bent knife showing laminated structure, Sringaverpur, Uttar Pradesh, India.

instance, a nail differs in composition from a knife or a dagger showing a selective use of carburization or quenching by the ancient iron workers. These technical skills must have been acquired over a long period before the craftsmen could have ventured to take up challenging jobs of manufacturing a 7-8 ton iron pillar that must have required skill of high order especially with its corrosion resistant property.

The colossal Delhi Iron Pillar (see Plate 4b) produced with approximately 7000 kg of wrought iron of fairly homogenized structure of over 98% purity. It shows an

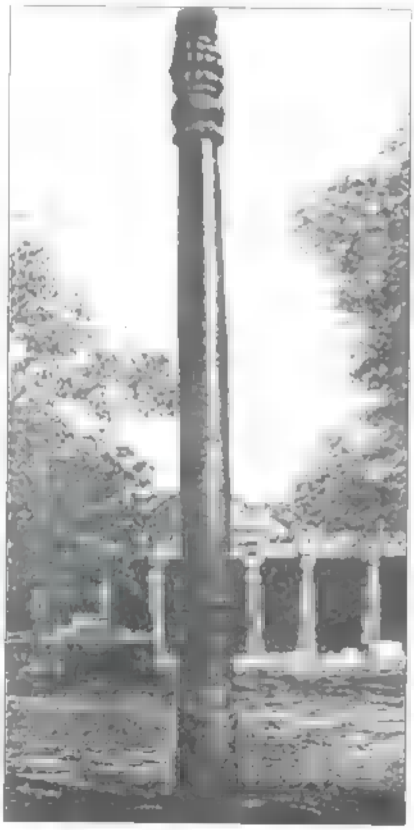

Plate 4b: Iron Pillar, Delhi, India.

expertise of high order and a capability of mass production of iron by 5^{th} - 6^{th} AD. As per published records, the largest iron making furnace of Nagpur (17th century pre-industrial furnace) could produce about 40 kg of iron per heat. (Prakash and Tripathi, 1986). The precise logistics have not been worked out but at least 200 furnaces of that size should have operated simultaneously or the same furnace operated repeatedly to produce that much iron of consistent quality to manufacture such a pillar (Balasubramaniam, 2008).

It appears that the artisans during the successive periods mastered the technique of forge-welding to manufacture colossal structures like pillars and beams. An examination of the fractured surface of the beams used in the Sun Temple at Konark in Orissa (see Plate 5a) clearly indicates that it was manufactured by

Plate 5a: Iron beams, Sun temple, Konark, India.

forge-welding square rods. Jena (cited by Prakash 1997) found traces of lead between rods, where the forging joint was not perfect. Large lead bath was said to be used for uniform heating of a bundle of wrought iron bars to the correct temperature and then forging them together. Since the iron surface is non-wettable by lead, normally it will flow out when the wrought iron bundle is taken out but some molten lead might get trapped in the crevices. Incidentally, some lead has been noticed also in Delhi Iron Pillar. (Balasubramaniam 2008).

Wootz or Damascus steel was famous and was in demand in the ancient world market. Generally this type of steely iron was being produced in the southern part of India. Beautiful swords with watering pattern on the surface were famous all over the world. The steel was being exported to Middle East from the ports of southern India. Pliny in Natural History, The encyclopedia of the Roman Empire mentions about import of iron and steel from Seres which has been identified with the ancient Cheras of south India. The Sangam literature also refers to a brisk trade with the Yavanas in the early centuries of the Common Era. Excavations like Arikamedu have shown presence of Roman artifacts. The Periplus of Erythrian Sea has also mentioned the Seres (Cheras?) shipped variety of commodities from the western coast like Muziri on the Malabar coast (Schoff 1912). We also hear about Seric iron that is significant in the present context. These references suggest trade in the famous wootz steel. There appear to be several sword making centers in other parts of India as well in the early centuries of Christian era as will be clear from the literary accounts (Tripathi, 2007: 403-426).

During the Early Medieval Age there must have been pressure on the artisan class to produce iron objects in a large number, especially to assist in the agricultural and war sectors. Though the archaeology of early medieval times is not very well documented, the rich literary evidence of the period does provide valuable data on the socio-economic life. We have already discussed the masterpieces like the Delhi iron pillars that belong to this age (4^{th} – 6^{th} century CE).

Victory pillars and monuments were erected to reiterate superiority and power of rulers of the age. Under these circumstances the industries capable of providing the tools, equipment, and weapons must have been much sought after. During this period, the demand for better, efficient and effective weapons for winning wars, tools and implements of masonry, building material, agricultural implements must have multiplied manifold.

Large sized structures of iron like pillars, beams etc. used in monumental buildings are found in several parts of the country. The frequently mentioned examples are the Delhi iron pillar of 5th century AD weighing over 6096 kg (nearly 7 tons) and the iron beams at Konark temple datable to 9th-10th century AD, which lie in several pieces in the temple complex. Its longest piece is 11,000 mm in length and 175 x 197 mm in cross section and weighs approximately 3000 kg (see plate 5a). Another noteworthy example is the victory pillar at Dhar that is said to be the biggest iron pillar in the country and perhaps anywhere in the world. It is broken in three parts during its transportation to a mosque by Dilawar Khan the governor of Allauddin Khilji in 1399 CE who tried to move it to another place.

What happened to such a developed iron industry during the succeeding period? This needs to be investigated closely. When the British arrived, their engineers systematically studied Indian iron working as they found a unique evidence of iron production in small workshops flourishing in several parts of India. It will be worthwhile throwing light on status of traditional Indian iron technology during this period.

III. Tradition of Iron Working and Its Survival in India

Both literary and ethnological evidences throw light on the status of iron till nearly pre-British period. There are Sanskrit texts composed up to 1400-1500 CE that speak of iron production and its trade.

In addition to this, the British period accounts and records give us a fair idea about the indigenous iron production that we plan to touch upon here. Some insight on this subject may be gained by literary accounts and ethnographic material brought to light from time to time.

III.1. Literary Accounts on Iron Working

The accounts of an Egyptian-Greek merchant in his book 'Periplus of Erythrian Sea' (Schoff 1912) testifies to the export of Indian iron to Abyssinia in the 1st half of the early centuries of the Christian era. Periplus gives a detailed account of the voyages undertaken by its author and the ports he had visited. The most important harbour was Barygaza, a corrupted Greek form of Bhrigukachchha (modern Broach or Bharoch) on the mouth of the river Narmada.

The technique of steel making was mastered as is evident from the textual data. As mentioned earlier, Varahmihir (550 AD) gives an elaborate description of carburization of sword blades. Such references bear this out that the artisan communities of 5th - 6th century AD had developed very complex processes of carburization and tempering. These processes must have already been in practice and were well established to find mention in important texts like the above one. Once perfected, the technique led to production of exclusive pieces that must have been in great demand in the contemporary world.

Scholar - kings like Bhoja of Dhar (1010-1053) had composed a text on iron metallurgy entitled Yuttkalpataru. Bhoja also acknowledges a presence of three earlier texts with the title Lauharnaua and Lauhadsp and Lauha Pradeepa. Agni Purana deals with weapons - types and techniques of manufacture of various weapons and centres famous for sword making. It also namesof port towns like from where commodities including swords were being exported. The ports mentioned there are: Surparak (Sopara) Vanga (Bengal) and Anga (Bhagalpur with its capital at Champa in Bihar). Ibn Haukal (HEID 1.37) mentioned the city of Debal in Sind as a famous sword making centre. Kurij in Kutch is said to be another such centre. However during the political turmoil that the Indian subcontinent faced during the medieval period took its toll on the preservation of such texts. With changing socio-political configurations iron technology receded into background from the centre stage. It was simply relegated to a low status and the metallurgy became a craft being possessed by the ethnic communities living close to the ore deposits in the forests. Over the period they were cut off from the mainstream of the Indian society. Nevertheless the metallurgical skill continued to be the prerogative of these communities till the British period as will be demonstrated in the statements of the British engineers and administrators who were surprised by the high quality iron and steel being produced by them.

Propagation
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The Geniza records of the eleventh and twelfth centuries bear testimony to the export of Deccan iron and steel to the Middle East. (Goitein 1966, 339). Fakhr-I-Mudabbir (11th Century AD) thought that the Indian swords were the best. The Damascene sword or Maujdarya was considered exclusive, even by the Arab world. It is said that these swords could fetch the highest price in the world market.

Plate 5b: Agaria furnace, Singaruli, Madhya Pradesh, India.

Special mention may be made here of *Ras Ratna Samuchchaya* (RRS), a 10th -12th century text on alchemy. A very fine classification of different types of iron has been attempted in *Ras Ratna Samuchchaya* showing a deep understanding of behaviour of iron in the smelting-refining process. Three basic types of iron with different sub-types (according to their properties, appearance and nature) have been categorised in RRS. There are three major types of iron, namely *Kant Lauha, Tikshna Lauha, Munda Lauha*. Each of these types of iron has several sub varieties. There is a list of fourteen (sub) types. Prakash (1991) and Biswas (2001) have tried to translate the terms of *RRS* in modern terms. These types of iron and steel were meant for different specific functions and usages. This shows the remarkable expertise mastered during the early mesievalmetal workers in India. It stands to reason to assume that a well-developed scientific basis existed in the ancient times as evident from some of these textual references.

Abhidhānaratnamālā, a text of this period, makes a list of metals that includes copper, bell metal, iron and steel, lead, tin, silver and gold. Different parts of the country were famous for different metals. *Agni Purana* (CCXLV. 21) describes five centres that were famous for sword making. They are *Khatikhattara* and *Rishika* (not identified so far), Surpāraka (Sopara), Vanga (Bengal) and Anga (Bhagalpur, Mungher districts of Bihar). Ibn Hauka", (HIED –1.37) mentions the city of Debal in Sind as a famous sword-making centre. Good quality swords were being produced also from iron or steel from Kurij in Kutch. These centres must have catered both to the local needs as well as to exports.

A fourteenth century AD work, *Sarangadhara Paddhati* (referred to by Joshi 1970: 82) by the alchemist *Sarangadhara* describes the technique of manufacturing swords.

The Asur and the Agaria tribes carried out this tradition of iron production. The ethnic societies have carried this legacy till the fifties in the 20th century. On investigation the British engineers found, as mentioned earlier, that the pieces produced by the Agaria, the traditional ironworkers were far superior to the British or Swedish iron.

"----bar iron…of most excellent quality, possessing all the desirable properties of malleability, ductility at different temperatures and of tenacity for all of which I think it cannot be surpassed by the best Swedish iron; ... the Agaria piece when brought to the bend it showed itself possessed of the power of elongating and stood the bend better than the general run of English iron purchased in the Bazar" (J. Franklin, 1829, quoted by Dharmpal 1971: 289).

Another instance worth mentioning here is the one mentioned by La Touché (1918),"...its (iron's) superiority is so marked, that at the time when the Britannia Tubular Bridge across the Menai Straits was under construction preference was given to use of iron produced in India". A good amount of iron was imported from India in construction of the above bridge.

Sir George Braidwood (1878 cited by Krishnan 1954: 70) recorded in the notebook of the British Indian section: "Indian steel was with such properties celebrated from the earliest antiquity and the blades of Damascus which maintain their pre-eminence even after the blades of Toledo became celebrated, were in fact made of Indian iron.....The Ondanique of Marco Polo's travels refers originally, as Col. Yule has shown, to Indian steel, the word being a corruption of the Persian Hindwany i.e. Indian steel. ---- the swords of Kirman were eagerly sought after in the 15th and 16th countries AD by the Turks who gave great prices for them. Arrian mentions Indian steel 'Sideros indicos' (that) was imported into Abyssinian ports"

After 'the Great Indian mutiny' in 1857, the British Government confiscated all the sharp edged weapons like swords, daggers and knives etc. kept by people. These weapons of the Moplas of Malabar made with native iron in the Indian blast furnaces are said to be of such high strength that it could not be shredded. It is said, "---and wonderful material they (iron objects) were. To break them was impossible, so a pair of strong hand-shears was made to cut them up. But the

remarkable point was this, that if put into the shears with the thin cutting edge first, they could not be cut at all, but notched the shear blades immediately", Charles Wood (1894: 179). The above statements are self sufficient to prove the saliency of Indian iron being produced by the indigenous iron workers in their clay furnaces till the British period. It may be construed from the above accounts spanning over several centuries that India had a rich tradition of iron working from the early centuries before Common Era that lasted right up to the pre-modern times.

III.2

The ethnic communities still reside in the remote parts of Vindhyan and Chota Nagpur plateau passing through several states from Uttar Pradesh to Chhattishgarh, Jharkhand and Odisha. Studies conducted by Elwin (1942), Leuva (1963) in Jharkhand, Chattisgarh, Ghosh et al. (1964) in Bihar and Orissa, Prakash and Igaki (1984: 172-185) at Bastar in Madhya Pradesh, Vikash Bharati, Jharkhand (Sharma, 1998) and our own work in Wadruffnagar and Sonbhadra, Sidhi region, revealed an adherence to rituals related to iron working processes. Ghosh (op. cit.) studied the ancient iron making sites of Chiglabecha and Kamarjoda in Orissa and at Jiragora in Bihar. Our own observations of the iron working in Sonbhadra-Sidhi region in UP-MP border in Vindhya-Kaimur hills is quite revealing (see Plate 5b: Tripathi 2001 for details). The metallurgical expertise was preserved by the ethnic communities who had traditionally pursued it as a profession till the British times but due to a variety of reasons like several other Indian crafts metallurgy also succumbed to the adverse socio-political condition.

It should now be our duty to save our heritage in the field of metallurgy by trying to document the surviving tradition and if possible to save our cultural heritage by providing them the basic facility to produce iron in their age old way with the raw material that is rated economically un-viable by the modern industries.

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Table 1: Radiocarbon Dates from Iron Age Level

Sl. No.	Sites	Radiocarbon dates in BP/BC on the basis of half life 5730 ± 40 years	Calibrated
Raja Nal - Ka –Tila			
1.	BS-1378 1996-97 Trench No. U - 19 (6) 1.95-2.00#m with iron	2626±110 BP 676±110 BC	822 (773) 486 BC
2.	PRL - 2047 1996-97 Trench No. U-20 (6) 2.08-2.10#m with iron	2980±90 BP 1030±90 BC	1196 BC-1188 BC -1164 BC-1143 BC -1132 BC-976 BC -970 BC-930 BC

Continued to next page

3.	BS – 1299 1995-96 Trench No. A-I Pit sealed by layer No. (6) with iron	2914 ± 100 BP 960 ± 100 BC	1118 (963) 859 BC
4.	BS – 1300 1995-96 Trench No. A-I (6) 2.00#m with iron	3150 ± 110 BP 1200 ± 110 BC	1423 (1307) 1144 BC
5.	PRL-2049 1996-97 Trench No. T-19 (6) 2.00#m with iron	3150 ± 90 BP 1200± 90 BC	1406 BC -1198 BC 1186 BC-1164 BC 1143 BC-1132 BC

Malhar

6.	BS - 1623, MLR II Trench No. XAI, Layer No. (3) Depth 0.55 cm	3550 ± 90	1886, 1664 1649, 1643 BC
7.	BS - 1593, MLR II Trench No. AI, Layer No. (3) Depth 90-100 cm	3650 ± 90	2010, 2001, 1977, 1750 BC
8.	BS-1590 MLR II Layer No. (4) 80 cm	3850 ± 80	2283, 2248, 2233, 2030 BC

Dadupur

9.	BS-1822 Trench No. DDR-3, A -I	3368 ± 80 BP 1420 ± 80 BC	1679 (1522) 1422 BC
10.	BS-1759 Trench No. DDR-3, A-1	3480 ± 160 BP 1530 ± 160 BC	1882 (1685) 1465 BC
11.	BS-1825 (Pit sealed by (12)	3532 ± 90 BP 1580 ± 90 BC	1739, 1706, 1695 BC

Lhuradewa

12.	BS-1939	2940 ± 100 BP	1205, 1205, 1188

Jhunsi

13.	AU/JHS/ 9 2075C-15 (46) 1210	2730 ± 90	897 (806) 789 BC
14.	AU/JHS/ 12 2077C-15 (49) 1240	2900 ± 90	1107 (973, 956, 941) 844 BC
15.	AU/JHS/ 16 2081C-15 (53) 1325	2780 ± 90	966 (830) 799 BC
16.	AU/JHS/ 18 2083C-15 (62) 1520	3290 ± 90	1597 (1490, 480, 1450) 1400 BC

Continued to next page

Aktha

17.	S - 3580	3350 ± 160 1660 ± 218	Un calibrated
18.	S - 3849	3460 ± 180 1771 ± 248	Un calibrated

Komaranhalli, Karnataka

19.	PRL - 46 (TL)	1320 ± 400	-----------------
20.	PRL - 47 (TL)	1380 ± 300	-----------------
21.	PRL - 47 (TL)	1200 ± 280	-----------------
22.	PRL - 49 (TL)	1130 ± 500	-----------------
23.	PRL - 50 (TL)	1440 ± 290	-----------------

Hallur, Karnataka

24.	TF - 570 (14C)	2970 ± 105 BP 1385 - 1050 BC	-----------------
25.	TF - 573 (14C)	2820 ± 100 BP 1125 - 825 BC	-----------------

Veerapuram, Andhra Pradesh

26.	PRL - 729 (^{14}C)	-----------------	1374 (1186, 1183, 1128) 921
27.	PRL - 729 (^{14}C)	-----------------	1293 (1047) 899
28.	PRL - 730 (^{14}C)	-----------------	1679 (1493, 1476, 1458) 1319

Vidarbha, Maharashtra

29.	PRL - 1361 (^{14}C)	2940 ± 160	1393 (1205, 1205, 1188, 1181, 1149, 1144, 1129) 917
30.	PRL - 1452 (^{14}C)	3080 ± 120	1490 (1381, 1334, 1321) 1131
31.	PRL - 1456 (^{14}C)	2820 ± 100	1185 (973, 956, 941) 834

Gufkral, Jammu & Kashmir

32.	-----------------	-----------------	1888 -1674
33.	-----------------	-----------------	2195 -1900

Charsadda, Pakistan

34.	-----------------	-----------------	1200 - 900

Table 2: Iron Objects at Different Cultural Stages

TOOL TYPES	NAME OF TOOLS	EARLY STAGE	MIDDILE STAGE	LATE STAGE
Hunting Tools	Spear heads	*	*	*
	Arrow heads	*	*	*
	Points	*	o	o
	Socketed tangs	*	o	o
	Blades	*	*	o
	Spear lances	o	*	o
	Dagger	o	*	*
	Sword	o	*	*
	Elephant goad	o	*	*
	Lances	×	×	*
	Armour	×	×	*
	Helmet	×	×	*
	Horse bits	×	×	*
	Caltrop	o	o	*
Agricultural Tools	Axes	*	*	*
	Sickles	*	*	*
	Spade	×	*	o
	Ploughshare	×	*	o
	Hoe	×	*	*
	Pick	o	o	*
Household objects	Knives	*	*	*
	Tongs	*	o	o
	Discs	×	*	o
	Rings	×	*	o
	Spoons	×	*	*
	Sieve	×	×	*
	Cauldron	×	×	*
	Bowls	×	×	*
	Dishes	×	×	*
Structural and craft tools	Rods	*	o	o
	Pins	*	o	o
	Nails	*	*	*
	Clamps	*	*	*
	Chisel	×	*	*
	Pipes	×	*	o
	Sockets	×	*	o
	Plump bob	×	*	o
	Chains	×	*	*
	Door hooks	×	*	*
	Door handle	×	×	*
	Hinges	×	×	*
	Spikes	×	×	*
	Tweezers	×	×	*
	Anvils	×	×	*
	Hammers	×	×	*
	Scissors	×	×	*
	Saw	×	×	*

Definite existence - * Confirmed data not available - o Non-existence ×

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The Need for Study of History & Philosophy of Science & Technology

Samir Kumar Saha & Siddhartha Ray

Abstract

*Science today has become an institution. But it can also be taken **(i)** as a method, **(ii)** as a cumulative tradition of knowledge **(iii)** as a major factor contributing to production of goods & services and **(iv)** as one of the most powerful influences moulding beliefs and attitudes to universe and man. And also, science has a social function. These points were raised and studied thoroughly by J. D. Bernal. Recently P. Fara has explained how science belongs to the real world of war, politics and business. She explores the sociological angle, arguing 'that being right is not always enough; if an idea has to prevail, people must say it is right.'*

The study of History of Science helps us to go beyond the definition: 'Science is experiment, observation and inference'. From a study of mankind's progress – we go beyond. From organisation of laboratories to public perception of science & technology to national politics, all are now studied in the broad discipline of history of science.

Understanding science is crucial to our understanding of nature and civilization as a whole – but there still remain questions unanswered. It is also important to distinguish between the various methods of arriving at truth - logical positivism, deduction, inductive method, falsification or paradigm shift. In many countries, science teaching is being deeply studied by philosophers of science.

The present world is at a crossroad. To create a knowledge society, to create innovative minds - it is important to understand the structure of scientific method. This paper explores these in some detail. Also, it is argued, history & philosophy of science have to be studied concurrently.

Introduction

This paper attempts to outline the needs for study of History of Science concurrently with Philosophy of Science. Partly, technology, whose growth is assisted by Science is also considered here, because, "Technology is used to conquer & control nature and make use of her for human welfare". It must be mentioned here, that this is where mankind failed partially. It is true that life expectancy has increased, food production and consumption has decreased starvation deaths, communication and travel have become faster , making networking among societies faster. But we are yet to resolve the conflicts among human beings leading to war, problems of unsustainability or the problem of greed leading to economic disorder. Are we paying the price for violating Francis Bacon's dictum, "Nature can be conquered only by obeying her"?

It is concluded that for innovations leading to knowledge societies without gender and culture bias and for a living planet with high sustainability index, studies of history & philosophy of science can be of immense help.

Science: The Meaning

In texts, science is defined as knowledge based on experiment, observation and inference. Historians of science have defined science integrating it with nature and society. Dampier defines science as ordered knowledge of natural phenomena and of the relations between them. It can be observed that the idea of interdisciplinary of subjects was inherent in most of those definitions.

For innovation, sustainability and transition to a knowledge society, interdisciplinary thought is a must. History of science is one such subject.

Why History of Science

The moot point is not, however, the definition of, but what science and technology have done for the society or world civilization? Of course they have created scientists

- A name coined by Whewell in 1840 in his book 'Philosophy of the Inductive Sciences'. Much later than Priests or Lawyers, scientists in the Mid-twentieth Century started being absorbed in Institutions
- Scientific laboratories or Universities. To this day, these institutions do not play leading role in governance in most societies. The question or problem needs to be addressed.

Science, to quote J.D. Bernal is a 'cumulative tradition of knowledge'. Scientists stand on earlier scientists shoulders. But this is not simple addition or a linear growth. This duality comes out only in history of science.

Science to technology to production has changed societal structures. But the off shoot of production has been a degradation of the environment. That too has been understood only in the 21st Century!

Methods of Science draw us to the philosophy of science. This will be taken up later.

Also, the interaction of science with culture and society is very crucial for the understanding of growth of science as well as society.

Broadly it can be taken as follows:

1. History of science enables us to understand the stupendous intellectual & innovative efforts scientists and technologists made through the centuries. It expresses the victory of collaboration and the collective spirit of men or groups of scientists cutting across borders

2. Scientific truths, being independent of space and time, are more universal. The culture of science is a global culture – a global intellectual treasure. The search for scientific truth is different than that of spiritual leaders. It takes time to establish a scientific truth.

3. A study of history of science as a discipline is needed to know about ideas, practices, innovations, events, individuals, groups and institutions that shaped science to trace the trajectory of this social and intellectual activity over time.

4. Why modern science did not grow in India? The history clearly shows that Greek Science owes its development to Egyptian and Babylonian Science. Indian science developed to a very high level between 400 and -900 A.D. This in turn helped Islamic Science which in turn influenced European Renaissance. The world was not Eurocentric or US Centric as it is now. What happened to Indian Culture -- which gave birth to scientific disciplines of Ayurveda, industries like metallurgy & ceramics, and made rapid strides? Answer needs to be found to this question.

5. History of Science builds a bridge between science and the humanities. The 'two cultures' dilemma may be solved with the study of such a subject.

There are many other needs for which the references can be consulted.

Philosophy of Science

Philosophy of science is concerned with the assumptions, foundations, methods and implications of science. It deals with very serious questions about the use and merit of science and tries to explore whether scientific results are actually a study of truth. Very often scientists and engineers question the necessity of handling these questions. Here we may quote physicist Richard Feynman ***"Philosophy of science is about as useful to scientists as ornithology is to birds"***. This is possibly an extreme view, and we may consider the view of Losee, which says: "***The distinction which has been indicated between science and philosophy of science is not a sharp one. This is based on a difference of intent rather than a difference of subject matter***".

What is the subject matter of Philosophy of Science?

1. Study of the difference between scientific knowledge and other types of knowledge. To distinguish science from non-science is one of the central themes of philosophy of Science.

2. Procedures or methods followed by the scientists to investigate nature.

3. Determination of correctness of scientific explanations.

4. Logical and rational basis of accepting the scientific laws and principles as truths. What we know as true today may not remain true at a future point of time.

5. Questions of ethics in practicing science. Questions are raised whether genetic engineering is good for mankind, how far it should go and where to stop. This is where theology is penetrating science questioning their basic tenets.

Study of Philosophy of Science helps us to explain how techniques of experimentation, observation and theory construction have enabled scientists to uncover the secrets of nature. It gives us an insight into how science should proceed, what methods of science should be used, what are the limitations of these methods and how much confidence is to be placed on the results obtained by following these methods.

Most importantly, it helps better to understand science and to show how by following the methods of science, the human mind opens up to innovations.

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We may briefly mention some of the methods of science:

(i) Deductive logic or reasoning: This is a process of reaching a valid conclusion following deductively from a given set of premises. A valid conclusion may be false if the premises are not true. Deductive reasoning is one of the old methods practiced by ancient Greek Philosophers like Aristotle.

(ii) Inductive method: This is a method of reaching a general principle or law from a number of specific observations. It states that if a situation holds in all observations, then the situation holds in all cases. A correct inductive argument may have true premises but a false conclusion.

(iii) Axiomatic system: It consists of a set of axioms from which by using some or all axioms together, a proposition or theorem can be derived logically. Euclid's Geometry is a classical example.

(iv) Positivism: This school of philosophy holds that the only authentic knowledge (or reality) is that which can be observed, detected and positively verified.

(v) Scientific realism and instrumentalism: Scientific realism claims that science aims to find out truth and scientific theories to be regarded as true or like true. The antirealist's or instrumentalist's view is that science does not aim at truth, and scientific theories should be regarded as useful to describe nature.

(vi) Scientific explanation: Scientific theories are expected to offer explanation of events that have already occurred, in addition to providing prediction of future events. Philosophers investigate whether a theory has successfully explained a phenomenon, as well as what gives a scientific theory explanatory power- the unification model and casual model proposed by Kitcher & Salman.

The list is long and need not be covered comprehensively within the short course of this deliberation. However, Karl Popper's "falsificationist" philosophy is worth mentioning. It begins with the universally accepted point that any amount of evidence can not prove a scientific hypothesis, because there are always untested predictions. Popper states that we should favour those hypotheses, which are falsifiable, yet unfalsified.

It is necessary to note some of the scientific thoughts in classical Indian philosophies in this context.

In Caraka Samhita, written somewhere about A.D. 300, origin of the deductive and inductive methods as well as experimental methods can be traced. Caraka also introduced concepts of heredity which are similar to our modem ideas on the subject.

Vaisesika Sutra, supposed to have been written by Kanada, is a philosophy of rigorous materialism. It believes in atomic structure of material and advocates a mechanistic theory of causation.

The Nyaya philosophers had criticized the self-validity of knowledge and established the theory of ascertainment of truth by verification. The major value of Nyaya philosophy consists in its contribution to method and precise terminology to be used in philosophical discourse, which was subsequently adopted by all schools of Indian philosophy.

Carvaka philosophy also known as Lokayata philosophy was a materialistic philosophy in contrast to other spiritual philosophies. Their views about origin of the world is that in the beginning being (life) came out of non-being, that matter is the ultimate reality. Lokayatikas deny past and future birth, all knowledge being posterior to and derived from experience. There is no second world, death is the end of all.

Orthodox Indian Philosophy Schools like Samkhya, Yoga, Vaisesika, Nyaya, Purva Mimamsa and Vedanta can be traced from Vedic and Upanisadic writings. Fundamental distinction of these spiritual schools are great though all believes in existence of Soul and its possible liberation, doctrine of Karma and Rebirth and acceptance of ultimate validity of Vedas. However dissenting views have also been expressed by the so-called many unorthodox Indian philosophies of which major are Buddhism, Jainism and the Carvaka or Lokayata.

Among Indian philosophers and scientists, Sri Akshay Kumar Dutt (1820-1886) was one of the first to oppose the metaphysical basis of Hindu philosophical texts and in his book 'Bharatbarsher Upasak Sampraday' (1870) he dealt with in depth, how hindu philosophy, mostly was neither empirical nor positivist. He consistently expressed that modern science was shaped in west and went into the reasons for it. Sir J.C. Bose (1858-1937), was one of the greatest scientists born in India. His work spanned from electromagnetic waves to nature of plant's life. However, even being an experimental scientist, his philosophical views were

metaphysical and 'Vedantic'. On the other hand Acharya Prafulla Chandra Ray (1861-1944), a great teacher, experimentalist and entrepreneur, wrote in his book 'History of Hindu Chemistry' (1904, p.195).

"The arts (technical) being thus relegated to the low castes and the professions made hereditary .... the intellectual portion of the community being thus withdrawn from active participation in the arts (technical), the how and why of phenomena – the coordination and effect – were lost sight of the spirit of enquiry gradually died out among a nation naturally prone to speculation and metaphysical subtleties and India for once bade adieu to experimental and inductive sciences ..... and (India's) her very name was all but expunged from the map of the scientific world." P.C. Ray mainly puts the onus on Sankaracharya's 'mayabad'.

As for Ramendra Sundar Trivedi (1864-1938), who was more a science populariser, than scientist – he wrote extensively on science and philosophy, and that too in very simple vernacular. He wrote extensively of philosophy in his book Jijnasa (1904) – where he writes in the essay 'Panchabhut' – "there is no need to combine philosophical analysis to scientific analysis. It is impossible." In the same book he discussed Buddhist philosophy which denied existence of Atma (Soul) in a separate essay. He was way ahead of his time.

An exhaustive study of Hindu Philosophy of Science was done by Prof. Brajendra Nath Seal (1864-1938) in his book "The positive sciences of Ancient Hindus' published in 1915. In p.39 (Sahitya Samsad Reprint, 2001), he writes "..... Vedanta and Purba-mimamsa has made some contribution (regarding basic tenets of chemistry, physics etc.); however overall it is negative." To understand Indian Philosophy of Science, this book is a 'must read'.

The writings of Debiprasad Chattopadhyay (1918-1993) must also be mentioned in this connection. He, a philosopher, and follower of Marxism, elaborated Indian philosophy's scientific basis and materialistic tradition in many of his books, particularly, 'Lokayata Darshan' (1956) and 'Science & Society in Ancient India' (1977).

Philosophy of Science has been given most importance in Marxist writings particularly in 'Diabetics of Nature' by Engels. According to him "dialectical thought is only the reflection of the motion through opposites which asserts itself everywhere in nature, and which by the continual conflict of the opposites and their final passage in one another, or into higher forms, determines the life of nature." Dialectics is central to Marxist philosophy of science.

A study of philosophy of science should include all these aspects.

Technical Questions

It was German engineers who, between 1775 and 1840's used the term 'technik' elaborating a discourse relating this term to philosophy, economics and culture. "Technik" meant the totality of tools, machines, systems and processes used in the practical arts (as technology was called in its early state) and engineering. Thus technology and engineering were differentiated long back. Now we use the terms interchangeably.

Lewis Mumford's landmark work "Technics & Civilisation" in 1934 talked about three different social systems developing, arising out of different technologies. He introduced the concept of technology complexes: the water-wood complex, the coal-iron complex and the electron-alloy complex. When we talk about knowledge society giving over-emphasis to Information and Communication technologies or Nanotechnology – where we talk about atomic nature, are we following the laws of obeying nature?

The questions central to Philosophy of Technology have been raised by David Nye [9] very comprehensively. Some of these questions help us to the study of History and Philosophy of Technology:

(i) Is technology deterministic or is it shaped by culture?

(ii) The predictability of technology.

(iii) Does using modern technologies break down or increase cultural differences?

(iv) The relationship between technology and nature.

(v) Does new technology destroy jobs or create new opportunities?

(vi) Should market decide the choice of new technologies?

(vii) Are advanced technologies leading to a more secure life?

(viii) Increasing technology use and its impact on human mental abilities.

Technology depends upon the technology to grow – it is self replicating. These questions bring scientists, technologies and the humanities people closer to understand what is good for civilization.

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Needed – A Course on History and Philosophy of Science and Technology

Sri Samarendranath Sen prepared a B.Sc. level syllabus on History of Science in 1960s in India. No University here wanted to run such a course. However, Asiatic Society did run a short term course for some time.

Abroad, we have many Universities, which run courses in History and Philosophy of Science and Technology.

It is imperative now that we start such a course in one of our Universities. Research in this area may lead to solving the problems of sustainability and the newer problems facing modern society.

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On Nehru's Concept of Scientific Temper of Mind and its Place in Modern India

K. Paddayya

Introduction

Notwithstanding some murmurs here and there, Jawaharlal Nehru is widely regarded as the principal architect of modern India. He was a man of vision and also possessed abilities to translate it into reality. Besides his well-known contributions to shaping of India's foreign policy, strengthening of the roots of parliamentary democracy, and development of industrial and agricultural sectors, Nehru laid special emphasis on the role of science and technology for chartering the country's development along modern lines. The latter contribution of his has been widely acclaimed in various circles. There is a related legacy of Nehru's which has unfortunately not been adequately acknowledged, much less acclaimed. This is his favourite and oft-repeated theme of the development of scientific temper of mind among the Indian people. In this essay I propose to give a short account of its nature and importance in contemporary India.

Nehru's autobiography gives clues about his interest in the dual aspects of science. He credits his boyhood tutor Ferdinand Brooks (of mixed Irish-French origin) for imprinting his young mind with a set of ideas that eventually shaped in a decisive way his Weltanschauung (Nehru 1989: 14-16). Brooks exposed the young and impressionable boy to metaphysical ideas by permitting him to attend weekly meetings of theosophists he used to organize in his rooms. Nehru states that he "gradually imbibed philosophical phraseology and ideas" and that "I owe a debt to him and to Theosophy" (Ibid.: 15-16). He credits Brooks with a second influence, which is about science. In Nehru's own words: "Brooks also initiated me into mysteries of science. We rigged up a laboratory and there I used to spend long and interesting hours working out experiments in elementary physics and chemistry" (Ibid.:14). His Natural Sciences Tripos from Cambridge University further strengthened his interest in sciences and, as he says, "I was influenced by my scientific studies in the university and had some of the assurance which science then possessed" (Ibid.: 21-22). His interest in socialist ideas was kindled by the writers of Fabian school. In subsequent years he read widely the works of writers like Russell, Bernal and Haldane and realized the importance of science and technology. So already in the 1930s on various occasions he was advocating the role of scientific methods and on this score he stood out among the other nationalist leaders who were waging a political struggle.

Considered against this background, it was but natural that, as the first Prime Minister of independent India, Nehru provided a big niche for science and technology, particularly in the development of industrial and agricultural sectors. His role in the establishment of various science laboratories in the country is well known. We are familiar too with the giant step he took in respect of science education by setting up the IITs. He not only religiously attended and addressed the inaugural sessions of the Indian Science Congress but held scientists themselves in great respect. During his visits abroad he made it a point to meet eminent persons like Einstein and John Dewey; he even offered Indian citizenship to Robert Oppenheimer when he was under duress in the U.S.

Scientific Temper of Mind

While Nehru rightly opted for a major role for science and technology to improve the material well-being of people, he surely did not lose sight of its significance for refining the Indian mind which is steeped in age-old dogmas and beliefs. It appears that here again the first seeds were sown by his tutor Brooks. We may recall here Nehru's exposure as a boy to lectures about theosophy and his interest in ancient Hindu and Buddhist texts, and the stress these writings laid on an unbiased mind. He was quick enough to realize that, while science and experimental method has unlimited potentialities for both exploring and exploiting the natural world, its basic tenets of rationality and proneness to reject ideas and beliefs not supported by positive facts have much wider implications and are of direct relevance for correcting, wherever necessary, and elevating the state of human mind. This is the core notion of his famous concept of Scientific Temper of Mind, which he saw as a necessary adjunct to the application of science and technology for developmental purposes. This became Nehru's second *Mantra* for India's development. He attached paramount importance to it both because he realized the need for freeing the mind from the mazeways of blind beliefs and dogmas in which it is caught and for preserving the linguistic, cultural, religious and ethnic diversity in the country which struck him as a historical fact thanks to his own voyages into the past, resulting in the writing of his widely read book *The Discovery of India* (Nehru 1960).

It is only sad that, although much has been said about Nehru's role to induct science and technology into nation-building activity, precious little has been written about his concept of scientific temper of mind and still less done to promote it in the society. In fact, even at top levels sometimes the true meaning of scientific temper has been missed. Many years ago I heard a Vice-Chairman of the U.G.C. treating a T.V. interviewer's question about scientific temper of mind as one on science itself and dispose it off as such. Khilnani's book The Idea of India, which rightly showers much praise on Nehru's role in nation-building, makes but only a passing reference to this topic (Khilnani 2004:180). From my limited familiarity with the literature I have been able to spot just two cases where attention was focused by writers exclusively on this topic. In October 1980 the Nehru Centre in Mumbai organized at Coonoor in Tamil Nadu a group meeting of about 25 eminent scientists and scholars on this topic under the chairmanship of P. N. Haksar and brought out a statement on this topic (Ramanna 1981). Some years later Nurul Hasan wrote a small but thoughtful paper on this concept (Hasan 1989).

Meaning

Stated briefly, by scientific temper Nehru meant a rational, objective and unprejudiced attitude of mind towards other persons and in all life-situations. As early as 1939 he stressed the importance of science for progress at individual and national levels and further defined science as "a certain way of approaching problems, a certain way of seeking the truth. It is a certain empirical way whereby we get prepared to reject anything, if we cannot establish or prove it" (*Collected Works*, Volume IX, p. 616). As the Prime Minister he gave expression to this theme on numerous occasions – addresses at the Annual Sessions of the Indian Science Congress, letters to Chief Ministers, public speeches, etc.

This theme found its clearest expression in his inaugural addresses at the Indian Science Congress, to which he not only attached great importance but lent strong support. These have been published as a separate volume entitled *Jawaharlal Nehru on Science* under the editorship of Baldev Singh (Singh 1986). Starting with his message to the Silver Jubilee Session held at Calcutta in 1938, Nehru addressed the Indian Science Congress on no less than 15 occasions from 1947 to 1963. It is useful to refer to a few of these addresses for grasping the true meaning of the concept of scientific temper of mind.

In his address at the Lucknow session held in 1953 he lamented that, while science has no doubt affected human life in a positive way, it has not made adequate impact on the human mind. This, he said, is the reason why people are "tied up in knots". He also bemoaned that, although they have excelled in their respective research endeavours, scientists as individuals still "accept or reject things without analysis, without criticism and without examination". He pointed out that a true scientist has on his shoulders the important task of promoting scientific temper among people, which he defined as the "critical faculty in considering problems, that evenness of temper, that objective way of looking at things which if enough of us cultivated would undoubtedly help tremendously in lessening tensions, national and international, and in going some way towards the solution of those problems" (Singh 1986: 38).

In his address at the Calcutta session in 1957 Nehru made a pointed reference to the Buddha's message of tolerance and his rejection of superstition, ritual and dogma. He further lamented that rigidity of dogma in religion and belief not only continues in the country but has in fact percolated into other spheres of life including politics and economics. In the inaugural address at the New Delhi session in 1959 he once again drew attention to the mismatch or gap between the dual aspects of science in modern times, i.e. while it has no doubt contributed enormously to the improvement of material well-being; it has not focused sufficient attention on reforming what he called "displaced minds". He warned that "Science is not merely looking at the heavens and at the microscopic things through its microscopes, not merely losing itself in the higher mathematics, not merely producing all kinds of calculating machines and brains ... But the fact remains that perhaps that misses something that is an essential part of the human being. And so science has also to look at the heart of human being, at the spirit and mind of the human being and try to integrate it with all the other advances it is making" (Singh 1986: 71-2).

In the address at the Madras session in 1958 Nehru went to the extent of advising the Science Congress to add to its proceedings a new section that will "probe into the ways of the human mind and the human spirit" (Singh 1986: 63-4). He also advised scientists to imbibe something of the wisdom of the sage and something of the compassion of the saint. He made a pointed reference to how non-scientists but spiritually guided persons like Gandhi and Vinoba influenced people's minds and emotions in the right way. Pointing out hat Indians are in the habit of imagining that they are more spiritual than others, Nehru

reminded that mere recitation of verses from ancient texts does not make oneself spiritual but it is the life that one leads.

During the tenure of Indira Gandhi as the Prime Minister, as part of the 42nd amendment to the Constitution, the promotion of scientific temper was added to the Directive Principles of State Policy. Thus Article 51A(H) enjoins upon every citizen of India "to develop the scientific temper, humanism and the spirit of inquiry and reform".

The Statement issued by the Nehru Centre in Mumbai lists four important attributes of scientific temper. Among these the third one is directly relevant to the theme of this essay. It states: "that the fullest use of the method of science in everyday life and in every aspect of human endeavour from ethics to politics and economics – is essential for ensuring human survival and progress" (Ramanna 1981:15). Emphasizing its importance in the Indian society, the Statement says that "Scientific Temper becomes a part of our culture, a philosophy, and a way of life which leads to pursuit of truth without prejudgement… Inherent in Scientific Temper is a system of value judgements. The inculcation of Scientific Temper in our society would result in our people becoming rational and objective, thereby generating a climate favouring an egalitarian, democratic, secular and universalist outlook …" (Ibid.: 16).

Place of Spirituality and Values

It is important to clarify that Nehru's emphasis on the role of science and technology in national reconstruction and the importance of scientific temper of mind in social conduct was not one of mechanistic application of science nor an argument for the use of cold reasoning in human affairs. On the contrary, prompted by his own not inconsiderable knowledge of Indian thought, he underlined the need for keeping in view the spiritual approach characteristic of the Indian mind and the values cherished by it. Nehru gave vent to this opinion on more than one occasion (Gopal 1984: 286-8). As mentioned before, in his address at the Madras session of the Indian Science Congress, he wanted the achievements of science to be tempered with the wisdom of sage and the compassion of saint. In a speech at Kolkata later in the same year, he even wanted a union between the truth-centered and experiment-based scientific approach and the spiritual approach forming part of Indian thought (Gopal 1984: 288). In a speech at Punjab University in 1959, he refuted the notion of incompatibility between natural sciences and humanities – a theme later developed in a more elaborate way by the British writer C.P. Snow for exposing the hollowness of two cultures proposition (Snow 1993). Later in the same year, in a speech at Teheran University, Nehru even stated that no science and industry could save a nation unless it adopted certain basic guidelines and human values. In an address to the Congress Parlimentary Party in 1963 he made a pointed reference to the complementarity between modernity and values derived from the past and cited the coexistence of atomic power plant at Trombay near Mumbai and the famous Trimurti figure of Elephanta caves, separated from each other by only a narrow strip of the Arabian Sea.

Conclusion

Now a few remarks about the degree or extent to which scientific temper of mind has permeated the Indian society. In his book *The Argumentative Indian* Amartya Sen has stated that the tradition of reasoning has been an ingredient of Indian mind ever since the dawn of history (Sen 2005). The dialogic method of the Upanishads is a well-known instance from the early period. The emperor Ashoka expressed in no uncertain words his displeasure against blind beliefs and superstitions. The Mughal emperor Akbar steadfastly upheld "the path of reason" (*rahi aql*) and said that his belief in Islam emanated from reasoning, not from "blind faith" and "marshy land of tradition" (*taqlid*) (Ali 1997).

But we all also know that over a period of many centuries the rational component of the Indian mind was largely submerged by thick accretions of myths, superstitions and obscurantist practices. Gandhi, while remaining true to his Hindu background, expressed in no uncertain terms his opposition to blind beliefs, wasteful rituals, temple evils and offering of prayers for selfish ends instead of cleansing and purification of the soul (Gandhi 1990; 39). It is precisely this veil enveloping the Indian mind which Nehru's concept of scientific temper sought to tear off. It will be incorrect to say that no efforts at all have been made by government agencies and voluntary organizations to spread scientific temper among people. For example, some years ago the Government of Maharashtra, thanks to the weight put in by organizations like Andhashraddha Nirmulan Samiti, has passed orders that persons advocating dogmatic beliefs and superstitious practices and misleading gullible people by these practices can be dealt with legally including arrest. But the fact remains that the progress is extremely tardy and various dogmas and superstitions still hold sway among both non-literate and literate sections of the society. For instance, both animal and human sacrifices are still being performed to propitiate malevolent deities. A recent example of "displaced

minds" in our society is the closure of the Indian Statistical Institute in Delhi for many days because the hostels and classrooms were 'haunted' by the ghost of a former student (as reported in *Times of India* dated 22nd September 2004).

There are many other deplorable manifestations of the phenomenon of "displaced minds". Gautam Adhikari's book *Unreasonable Indians* (2010) has drawn attention to the increasing loss of reasoning among political parties. The electronic and print media, instead of correcting the minds, are actually promoting their corruption by permitting advertisements which announce the sale of things like 'Lakshmi-yantras' that supposedly ensure wealth. Godmen and their misdeeds are well known. The gigantic leap in corruption in money matters in higher levels of the society has become a national concern.

In view of these circumstances the role of scientific temper of mind has now become more relevant in the functioning of our society. It needs to be promoted by all available means and at all levels. It deserves a prominent place in our value education programmes at school and college levels. A whole corpus of concepts drawn from sources ranging from the Upanishads and Buddhist and Jain streams of thought to Asoka's Dhamma policy to Sikhism, teachings of medieval saints and precepts of Akbar's unfortunately short-lived Din-Ilahi or divine monotheism including the concept of sulh-i kul or Absolute Peace (Khan 1997) could form part of this value education.

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Expanding the Role of Educators in Science Museums

Gretchen Jennings

Abstract

In 2007 the word "education" made its way to first place in the list of museum goals published by the International Council of Museums (ICOM). As someone who began museum work as an educator some thirty years ago, I am happy to see education and its attendant goals of public service and community engagement receive acknowledgement in the international museum community. At the same time I am concerned both about the way that education has been defined and perceived in museums and subsequently about the role that museum educators play. This article is based on my 30 years of experience working in and with museums, especially science centers, in the United States; my visits to some dozen museums and science centers in India during my NCSM-sponsored travels in 2009 and 2011; and reflections from my blog, Museum Commons, which I began writing in June 2011[i].

Education and the Public Dimension: A Brief History

The International Stage

Since its creation in 1946, ICOM has repeatedly revised its definition of the word "museum." A close examination of these definitions on the ICOM website[ii] provides a thumbnail sketch of changes not only in museums but in world culture, e.g. references to "man" become references to "humanity," and "collections" have become "tangible and intangible heritage." The following three ICOM definitions illustrate the growing perception of museums as institutions created for education and service to society:

> 1946: The word "museum" includes all collections open to the public, of artistic, technical, scientific, historical or archaeological material, including zoos and botanical gardens, but excluding libraries, except in so far as they maintain permanent exhibition rooms.
>
> 1974: A museum (science centres, planetaria, etc. were added in a lengthy addendum to this definition) is a non-profit making, permanent institution in the service of the society and its development, and open to the public, which acquires, conserves, researches, communicates, and exhibits, for purposes of study, education and enjoyment, material evidence of man and his environment. (Here we see that "education" appears, along with "study" and "enjoyment" as one of the main purposes of a museum.)
>
> 2007: A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment. (Here "education" attains first place.)

In American Museums

The use of the term "public dimension" with its focus on education as a primary aim of museums came into its own in the United States with the American Association of Museum's publication in 1992 of *Excellence and Equity: Education and the Public Dimension of Museums*[iii]. This report, created by a commission of leading American museum directors, educators, and curators, is considered a landmark document, and has had an enormous impact on American museums of all types – history, art, and science. A quick online search of American museum mission statements reveals words such as *educate, encourage learning or appreciation, inspire, public service, public, community*; all larger museums today have education departments, and even very small museums often count as part of their essential staff an educator as well as a curator or conservator. The recommendations of *Excellence and Equity* regarding the role that museums should play in education and public engagement were guaranteed sustainability when AAM began to include a "Public Dimension" section in its criteria for museum accreditation and re-accreditation. Any museum seeking the stamp of AAM on its mission and work must meet a range of standards that include not only management and collections criteria, but a commitment in staff, budget, and programming to "the public dimension."

Why the Concern?

Education and the concept of the public dimension seem to be almost everywhere in museum discourse and museum practice. With all of this affirmation of the educational role of museums, why then am I concerned?

Concern 1: Importing a Classroom Mentality

I have been thinking for some time about museums' propensity to imitate and reinforce the environments and methods of formal education in the roles they assign educators and in the ways they apply education in

Propagation
A Journal of Science Communication

their work. For a variety of reasons, the acknowledgement of education's primary role in the work of museums has led to a narrower and narrower definition of the word "education." One reason may be that people generally tend to equate education with schooling. Another may be that many education staff in museums come from the formal education sector, are comfortable with its perspectives and methodologies, and have transferred them into the museum world without much modification. Finally, the collaboration of schools and museums certainly brings both tangible and intangible benefits - funding for museums and curriculum enrichment for schools. In particular because of these mutually beneficial relationships, I do not think that museums should abandon their school constituents. I do, however, advocate a closer look at the broader question of museum learning, which can include but should not be limited to links with the world of formal education.

Despite their classrooms, museum teachers, and programs for students, museums are not at their roots alternative schools. They are specially designed spaces that encourage engagement with three dimensional objects and/or activities; that move people through time and space; that involve graphic design, lighting, staging, and social interaction. If anything museums are more like the theater than they are like schools, but that is another discussion.

Impact of Narrow View of Education on Role of Education Staff in Museums

As a consequence of this linking of museum education almost exclusively with service to schools and students, the role of museum educators is very narrowly focused in many museums. Certainly this is true in the United States, and I suspect it is the same in India. The work of educators consists in the development of training and materials that will educate teachers about the museum and its offerings and enhance school visits. Although many museums now include educators on exhibition development teams, their role is often limited to the creation of programs and materials that will enhance visitor and school experiences. Their primary responsibilities are fulfilled after the exhibition is conceived and developed, and their participation in the creation of the exhibition itself is minimal. While theirs is not an insignificant or unimportant role, it does raise questions about why, if museums are primarily learning institutions, educators might not also contribute to museums' primary mode of communication - the exhibition. My sense is that in most museums with curators, it is the curators who still make major decisions about the content and format of exhibitions and about the overall vision of the museum. And in museums without curators, such as many American science centers, it is the exhibit department that is the most influential in shaping the overall direction of the museum.

Thus it is important to acknowledge the persistent secondary status of education staff in most museums. Granted there are some exceptions, but in most museums people with this type of expertise may head an Education Department; they are not necessarily part of top management. They have input, sometimes considerable input, but do not ultimately control the direction of the museum. How many have final control over museum resources - funding, staff, space, and time? How many make the final decisions about the distribution and use of these resources? How many have a major impact on Board decisions? On the direction of new fund-raising? I don't mean to belittle the successes that my fellow museum educators have achieved in advocating for the public dimension over the years. But, as one experienced colleague put it when I discussed this topic with her - "[museum educators] have changed the identity of museums, but perhaps have not gained power."

Why the Secondary Status?

Among the causes for this secondary status:

* In the long history of museums, educators are relative newcomers. Curators have been a part of museum structure almost since their inception. Despite education moving to the forefront of museum goals, as discussed above, the internal structures of most museums remain the same. Education Departments have been added, but their directors and most especially their staff, do not have a place in the hierarchy that is parallel to curators, even when the educators have higher degrees comparable to those of curators. Some museums have made an attempt to change this by calling their Director of Education the "Curator of Education," but these are few and far between.

* It must also be acknowledged that the museum world is still a male-dominated one - except in the area of education. In the United States, at least, most Education Departments are headed and staffed by women. But if one looks at statistics on museum directors and senior administrators, the numbers show that they are overwhelmingly male.[v] In my view gender bias is still alive and well in the museum world.

* The narrow concentration of museum education departments on work with schools instead of on exhibitions, the central focus of most museums

and their *raison d'etre*, also undermines their recognition as essential to the central work of the museum. This is discussed at greater length elsewhere in this paper.

My view is that in absence of a widening of their purview, museum educators will continue to have great difficulty in effecting a pervasive and fundamental impact on the institutions in which they work. And most of our museums, exhibitions, and programs will continue to look and operate pretty much the same as they always have.

Looking at Learning Rather than Education

A simple shift from the word "education" to the more active term, "learning," may help to widen our perspective. Certainly the current research on experiences both in schools and in museums focuses on learning. I have found a number of publications by the National Research Council (NRC) of the National Academies of Science in the United States to be useful in exploring this broader concept of learning, especially as it is understood in museums. These publications are available free online.

Distinction between Formal and Informal Learning

Distinctions between formal and informal[v] learning are not helpful, and may be misleading. *How People Learn* by cognitive scientist John Bransford and colleagues[vi] provides a compendium of recent scholarship on learning. The studies discussed by Bransford confirm that the experience of learning is essentially the same, neurologically, psychologically, and cognitively, in both formal and informal settings. Whether in a classroom, a park, a kitchen, or a museum, the process, as it happens in the brain, is the same. The neurons are firing, the synapses are connecting, and change (learning) occurs. Bransford says that all learning is transfer; it is change - we gain new information, or expertise, or skills. The conditions that promote learning are also the same, whether in a formal or informal environment. We learn best when we can relate something new to what we already know. Learning is enhanced (or inhibited) by context, by prior knowledge, by communication with others, by discussion and scaffolding. The distinction that is often made by museum professionals regarding formal and informal learning/education is not a useful one; it is the environments (classroom or kitchen) in which we learn, and the methods (testing, memorizing, tasting, touching, etc.) we use, that are formal or informal, not the learning process itself. This distinction, I think, may help in re-imagining the role of science museum educators, who should be viewed as the experts when it comes to developing learning experiences for visitors in informal settings.

Museums as Intentionally Designed Spaces

A second NRC publication, Learning Science in Informal Environments[vii] is a useful companion to Bransford. The report, published in 2009, summarizes and organizes current research on learning science in informal settings, including museums. Chapter 5, "Science Learning in Designed Settings," describes museums as environments that are "intentionally designed for learning about science and the physical and natural world."[viii] The report goes on to give examples of intentionally designed spaces for science learning - science museums and centers, aquariums, zoos, environmental centers and their designed components. Using an array of current research, *Learning Science in Informal Environments* describes the kinds of experience visitors can have in settings designed for science learning. These range from the concrete – new understanding of a scientific concept, for example – to the more abstract – excitement and enthusiasm about science and the natural world; personal meaning-making; a reinforced sense of identity; a more spiritual connection with nature.

In its discussion of museums as intentionally designed spaces the report observes that "science exhibit design can be both a form of interpretation and a catalyst for science learning." Exhibits that encourage science learning should:

- be shaped by intentional design & personal interpretation (prior knowledge);
- stimulate excitement, interest & comfort;
- feature direct experience and direct access to phenomena;
- model scientific processes through interactivity; doing and seeing; meaning making and explanation (stimulate prior knowledge); questioning and predicting; self-reflection on learning;
- be designed to encourage adult-child interaction.

Museum Educators as Experts in Developing Informal Spaces for Science Learning

It is in this broader rethinking of learning in museums that I see museum educators have an important role. If we think of science exhibitions as intentionally designed

informal spaces for science learning (very different from the classroom or laboratory formal spaces for science learning) then museum educators, experts in human learning, should move to an important role in the design of exhibitions. Curators are still vitally important in the research and contribution of content; exhibit designers are also essential for their technical knowledge of the manipulation of museum space; but educators are equally necessary in order to inform and shape the ways that content and design come together to enhance engagement not only by students but by the visitors of all ages who come to museums, usually in multigenerational groups.

The following are some specific ways in which museum educators can make significant contributions to the design of informal spaces in science museums.

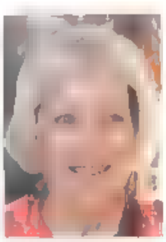
- Museum educators know visitors well and are at ease in working with them on the museum floor. Working with curators and exhibit designers, they *can design and conduct formative evaluation for potential exhibition projects* - observing and interviewing visitors in order to ascertain what they do and do not understand about concepts and terms under consideration for an exhibition.
- Once formative evaluation is completed, *educators can analyze the findings and use them to advise curators and exhibit designers on ways of displaying science concepts* so they can be understood by the broadest range of visitors.
- Museum educators are trained in a *developmental understanding of learning*, i.e. they know through both training and experience that people of different ages have different levels of skill and ability. Educators are used to adapting difficult material to differing age groups for maximum understanding. They *should be involved in writing or at least reviewing label copy that is developmentally appropriate* and accessible to children, adults, and family groups.
- Museum educators can also contribute to exhibition development *by working with the exhibit designer to organize and conduct prototyping* of exhibit designs and components with visitors on the museum floor.
- Museum educators *can be trained to conduct more sophisticated forms of visitor research, thus benefiting the museum in its future planning.*

Conclusion

Educators, despite their universally acknowledged key role in the essential work of museums, are an under-used and under-appreciated resource in science centers and museums. Directors and administrators should expand and foster through training the involvement of educators in all aspects of their institutional mission and not simply in the organization and conduct of school programs. Educators should be involved in the important work of exhibition assessment and development and more broadly in planning for the future of their institutions.

Notes

(I) Museum Commons. http://museumcommons.blogspot.com/
(ii) Development of the Museum Definition according to ICOM Statutes (2007-1946). Retrieved February 19, 2011 from http://archives.icom.museum/hist_def_eng.html
(iii) American Association of Museums. (1992). Excellence and Equity: Education and the Public Dimension of Museums. Washington, DC: American Association of Museums.
(iv) Norris, L. (Nov. 3, 2011). Want to be a museum director? Apparently, be a man. *The uncataloged museum* blog. Retrieved February 1, 2012 from http://uncatalogedmuseum.blogspot.com/search/label/leadership.
(v) In the United States the phrase "non formal learning" is rarely used. "Informal learning" is the standard phrase to refer to the kind of learning that happens in museums or actually in any non-school setting and is used in this sense throughout the article.
(vi) Bransford, J. et al. (2000). *How people learn.* National Research Council. National Academies Press. Retrieved January 9, 2012 from http://www.nap.edu/catalog.php?record_id=9853
(vii) Bell, P. et al. (2009). *Learning science in informal environments: people, places, and pursuits.* National Research Council. National Academies Press. Retrieved January 9, 2012 from http://www.nap.edu/catalog.php?record_id=12190
(viii) Bell et al. p. 127.



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Marie Curie – An Immortal Life in Science

Syamal Chakrabarti

Family Background

Marie Curie, one of the greatest scientists of all time was born on November 7, 1867. Her father's name was Wladyslaw Sklodowski and mother, Bronislawa. She was the fifth and last child of the family. Poland was then under the rule of the Russian Tzars. There were two uprisings, one in November 1830 and the second one in January 1863, which led to the exile and imprisonment of Poles on a vast scale. Mother Bronislawa was the headmistress of a private school, one of the best schools for girls in Warsaw. She was married during summer 1860 and used to live in an apartment adjacent to her school. The couple lived there for seven years. Mdm. Bronislawa bore five children : Zofia in 1862, Jozef in 1863, Bronislawa in 1865, Helena in 1866 and finally Maria in 1867.

During January 1863 uprising, Wladyslaw's brother Zdzislaw, twice wounded in the fighting, fled to France. Bronislawa's brother Henryk, who also fought in the rebellion, was exiled in Siberia for four years. Wladyslaw's father also fought in the November 1830 uprising, and was driven on foot, 140 miles north of Warsaw. However, later, he resumed his career as a teacher. He, as head of the school, insisted that talented peasants should be allowed to study with the children of the nobility. This was simply unbelievable at that time!
Thus Maria's family, both from mother and father's end, had a long political tradition.

What was the fate of the Poles in Russian Poland?

'...if he studies law, he can never become a judge, generally not even an official, without separating himself from all intercourse with his countrymen. If he studies medicine, he can never obtain a post at a university, never be at the head of a hospital, never conduct a public clinic. The result is ... he has no real mastery of anything.'

George Brandes
Danish Observer

However, science fascinated Maria's father. Maria noted, 'My father enjoyed giving explanation about Nature. Unhappily, he had no laboratory and could not perform experiments.'

What was his educational qualification? He never studied abroad or obtained any university degree. After the uprising of November 1830, the Russians closed down Warsaw University. However, Wladyslaw studied biology in Warsaw, graduating from 'biology department' without having any official status. He used to teach biology to his own children.

The family moved from the apartment adjacent to the school in 1868. A great tragedy came into the family. Mother Bronislawa died in 1878 from tuberculosis. She was out of home for treatment when Maria was five years old only. After leaving her teaching job, Bronislawa taught herself shoe making. She then opened a little shop in her apartment without any resentment for doing the so-called 'low' occupation of a cobbler.

The family used to spend vacation with their relatives in countrysides. Maria wrote later, 'I owe my love for the country and nature.' She lost her mother at ten years of her age. She had also found the tragic demise of her eldest sister Zofia two years and three months before her mother's death.

Her Education in Poland

Maria got admission at the school where her mother was a teacher. She and Helena opted for a new school in their third grade class. Helena was ten and Maria was nine then. Maria was youngest in her class. She influenced her classmates with her unusual intelligence and exceptional memory. All of her friends respected her and often asked for help in mathematics and other difficult subjects.

Maria Sklodowska graduated from Gymnasium Number Three in 1883. Jozef, their only brother, went to Medical school at Warsaw University. Admission of women in Warsaw University was forbidden at that time. What can Maria do now? She can study abroad, Paris or St. Petersburg, or she can be a teacher like her mother. What happened really?

She took almost a year's rest in the country. She boarded a train and left Warsaw for an extended visit with her maternal uncles. It was a total leisure for her. She wrote '...I have no schedule. I get up sometimes at ten o'clock, sometimes at four or five (morning, not evening!). I read no serious books, only harmless and absurd little novels...'
Maria, in her younger days, was largely influenced by positivism. Auguste Comte, the originator of the idea conceived positivism as a sort of religion whereas

Polish positivism embraced empiricism and rejected the metaphysical part of it. Comte was a believer of 'natural inferiority' of women. The polish positivists were enthusiastic supporters of women's rights.

Some of our readers may not believe the following facts now-a-days.

There was an education academy for the young Polish women which started running from 1882. Two hundred young Polish women used to meet secretly in the private apartment of the supporters where they were taught by prominent Warsaw scientists, philosophers and historians of Polish literature and culture. Somehow, Russian Police got the information and most of the teachers in the academy were forced to leave Warsaw. Maria was involved in the secret academy from its inception. Maria and Bronia, after graduation, began to take courses. In 1886, the academy became a university known as Flying University. By 1889-90, a thousand women were enrolled in Flying University.

After taking courses for one year, she decided to take a job as a governess in the family of lawyers. The family members were simply unbearable.

Maria wrote, 'I learned to know the human race a little better by being there. I learned that the characters described in novels really do exist. One must not enter into contact with people who have been demoralized by wealth.'

This kind of daily-life can not go on for ever. Bronia and Maria made a plan. Bronia will go for study in Paris within a year. Maria will continue as governess for helping Bronia and her father. Once Bronia is established, Maria will follow her.

Maria worked for four years as a governess. During this period, Maria used to teach a group of polish peasant children. She also continued her self-education. She studied Daniel's Physics, Spencer's Sociology (in French), Paul Bers' Lessons on Anatomy and Physiology (in Russian). She kept her habit of solving algebra and trigonometry.

Maria wrote, 'I was as much interested in literature and sociology as in science... I finally turned towards mathematics and physics.'

One of Maria's cousin, fourteen years older than her, had returned to Poland after studying in Russia with Mendeleev. He became the director of a positivist-influenced institution named 'Museum of Industry and Agriculture' (1875). There was a chemistry laboratory in the museum. She was allowed to work over there. She wrote in her autobiographical notes :

'I tried out various experiments described in treatises on physics and chemistry. The results were sometimes unexpected. There were also accidents and failures resulting from my inexperience.'

French biologist Claude Bernard (1813-1878) was her hero. Bernard is considered to be the 'father of modern experimental physiology'. Probably because of her free access in the chemistry laboratory, she opted for chemistry and physics over biology when she arrived in Paris.

Her Life in France

Bronia got her medical degree in 1891 and started practicing in Paris with her physician husband. Maria came to Paris during November 1891. That time, women still could not bear witness in a civil suit and could not spend their own earnings without their husband's permission. Maria took admission in Sorbonne and got *licence ès sciences* in 1893 (one out of two female licence recipients in the whole university) and *licence ès mathèmatiques* in 1894 (one out of five recipients in the whole university). A total of sixteen professors taught her. Eight were so famous that their names are found in the current Dictionary of Scientific Biography. Maria stood first in the *licence ès sciences* and second in the *licence ès mathèmatiques.*

After sometime, in the spring of 1894, she met Pierre Curie (1859-1906) who was then conducting experiments on magnetism. By that time, he had already invented a number of delicate measuring instruments. Lord Kelvin appreciated Pierre for his original contribution to the understanding of heat and work. He was a teacher in the *E'cole municipale de physique et chimie industrielle* and was least interested to submit a thesis for Ph D degree. However, Pierre presented his thesis at the Sorbonne in March 1895 and obtained Ph D shortly. Maria and Pierre married on July 26, 1895.

They were not slaves of fashion but loved bicycling. When they were in Paris, they used their bicycles whenever possible. Pierre and Maria's yearly combined income was six thousand francs, roughly three times of a school teacher and four times that of a laborer. Their income did not permit them to have servants.

Right from the very beginning, they used to do research together. Irene was born on September 12, 1897. After two months, Maria took a nurse. She wrote her father on November 10, 1897 : 'I don't want to interfere with my child's development for anything on earth.'

At the same time, her devotion for research was beyond any question. She wrote a paper 'On Magnetism of Tempered Steels' for the 'Bulletin of the Society for the Encouragement of National Industry.' It was her first published article. She concentrated on her work for submission of her PhD thesis. Eminent French physicist Henri Becquerel discovered 'radioactivity' in March 1896. She decided to work on the same though the subject was little known at that time. Pierre Curie also joined in this endevour.

They were the first to invent a highly sensitive radioactivity measuring instrument. In fact, they made an 'ionization chamber' from the left over wooden grocery crates. Inside, they introduced two circular metal plates, eight centimeters in diameter, one above the other, separated by three centimeters. On the lower plate, they placed a thin layer of the substance in question. Then they charged the lower plate with a high-voltage battery. If the substance on the plate was a conductor through air, the upper plate would gradually be charged. She first experimented with white Uranium powder obtained from Henri Moissan (NL 1906). Then she collected samples haphazardly from her colleagues around. She had detail note-books on her experiments. On February 10, 1989, she tested 13 elements including Gold and Copper. None of them produced currents as evidenced from the deflection pattern of the electrometer.

Golden Time Ahead

On February 17, 1898, she tested a heavy black pitchy mineral known as pitchblende, a mineral of Uranium. Longtime back in 1789, a self-taught chemist Martin Heinrich Klaproth extracted Uranium from this mineral. The element was used as a colouring agent in ceramics.

Marie Curie found that the mineral produces stronger current than Uranium alone. She was puzzled. Next day, she tried with several Uranium compounds as well as Uranium and pitchblende. Compounds are less active than pure Uranium. But pitchblende is more active.

On February 24, 1898, she experimented with the mineral aeschynite which contains thorium but no Uranium. It is also found to be more active than Uranium. Thorium was discovered by J. J. Berzelius in 1828.

Observation I : Thorium is more active than Uranium.

Observation II : Pitchblende is more active than either of the two.

During that period, Pierre had been turned down a professorship at Sorbonne. Jean Perrin, twelve years younger than him, got the job. Charles Friedel, who proposed Pierre's name wrote a letter to him :
'... what can one do against a normalien? ... do good work in physical chemistry in order to show these messieurs...'

The couple did not care the rejection. Pierre was then working with crystals. He left that research and joined Madam Curie (Note Book : March 18, 1898).

Why pitchblende is more active? It must contain new radioactive elements. Curies performed another experiment in between. They measured the activity of natural chalcolite. They synthesized the same by adding Uranium and Copper phosphate and compared the activity of natural chalcolite with artificial chalcolite. It was found that the latter shows less activity than Uranium. Their immediate conclusion : Natural chalcolite contains an element more active than Uranium.

In Search of New Elements

Marie Curie read a paper in the Academy titled 'Rays emitted by Uranium and Thorium compounds.' As Marie and Pierre were not the members of the Academy, the paper was read by Gabriel Lippmann, a teacher of Marie at Sorbonne. This paper was not only of finding new elements but proposed two much more important findings:

a) Novelty into physics : radioactive properties are a diagnostic for the discovery of new substances (Abraham Pais : Inward Bound).

b) As activity was found to be proportional with the amount of Uranium or Thorium, radioactivity is an atomic phenomenon.

Marie and Pierre started working with 100 gm of pitchblende. They treated the mineral with so many chemicals. They measured activity of each fraction. The fraction having highest activity was put under

spectroscopy. No definite spectra was observed because of impurities. They invited Gustave Bemont, a chemist, to help in separation. The sample was divided into two parts. Marie got something which is 300 times active than Uranium. Pierre got 330 times active material. They performed spectroscopy. Again results are disappointing. Finally they got a part which is 400 times more active. They named it as 'Polonium' (July 13, 1898). The paper entitled 'On a New Radio-active Substance contained in Pitchblende'.

After that, there was no work for three months due to the shortage of minerals. The work again started in November 1898. They got a part which is 900 times active than Uranium. This time spectroscopy worked. A characteristic spectral line was found which was not known before.

In the note book, on 20th December 1898, Pierre marked prominently a name, 'Radium'. A paper titled 'On a New Strongly Radio-active Substance contained in Pitchblende' was read on December 26, 1898.

From the beginning of the new year, they divided their searching area. Madame decided to isolate 'Radium'. (act of a chemist). Pierre decided to find out the cause of radioactivity (act of a physicist). We cite a revealing statement from Irene :
'... it was my mother who had no fear of throwing herself, without personnel, without money, without supplies, with a warehouse for a laboratory, into daunting task of treating kilos pitchblende in order to concentrate and isolate radium.' Marie had to work with 20 kgs of material at a time.

Marie wrote, '...we were very happy ... we passed our days at the laboratory, often eating a simple student's lunch there. When we were cold, a cup of hot tea ... cheered us. We lived in a preoccupation as complete as that of a dream.' Their financial position was miserable. Marie wrote to her brother Jozef (March 1899) :
'...my husband's salary is not quite enough for us to live on. ... we have had some unexpected extra resources (i.e., prizes) every year, which keeps us from having a deficit.'

After four long years of continuous work, in July 1902, Marie Curie announced that she had isolated one decigram of radium. We all know, radium is spontaneously luminous but it was not known to the Curies that it had a deadly potential. Their notebooks are undoubtedly very precious documents but even today they are full of radiations.

1899 and 1900 were very fruitful years. Marie wrote two papers on isolation of radium. Pierre wrote one on the effect of magnetic field on radium emission. There were three joint papers where they reported 'induced' radioactivity and electric charge of certain radium rays.

International Congress of Physics, Paris and after

Scientists from Austria, Britain, Germany, Hungary, Italy, Japan, Russia, Scandinavia, Switzerland & United States attended the congress. India also participated. Lord Kelvin, H.A. Lorentz, van't Hoff and Arrhenius were also present.

Curies read their longest paper 'The New Radioactive Substances' in the congress. They told everything except the source of energy of the 'Becquerel rays' as it was then completely unknown. Curies themselves raised the question in their paper :
'What is the source of energy coming from the Becquerel rays? Does it come from within the radioactive bodies, or from outside them?' Gravitational and electromagnetic forces (due to Newton and Maxwell) were known that time. But we had no idea about nuclear force. Marie, few years earlier, in her first paper suggested 'all of space is traversed by rays...which can only be absorbed by certain elements of high atomic weight, like Uranium & Thorium.' It means energy is brought to the radioactive substances from outside. Is it a fact?

Rutherford in January 1899, suggested that radioactive emissions are made up of at least two different kind of rays, 'beta rays' and 'alpha rays'. Madame Curie, Pierre Currie and Henry Becquerel concluded that Rutherford's 'beta particles' are identical with Professor Thomson's negatively charged particles. By 1903, Rutherford and Soddy finally proved that radioactivity is a nuclear phenomenon. It opened up the area of nuclear physics.

It is interesting to note that at the beginning, Marie was a non-believer of radioactive disintegration. However in 1906, she published a paper which shows that Polonium loses half of its activity after 140 days.

Curies got an offer in 1900 from the University of Geneva. However, they decided to stay in France. In the same year, Marie became the first woman in the faculty of the Ecole normale superieure at Sevres. It was known as country's best preparatory school for women teachers. Pierre got an offer to teach physics,

chemistry and natural history to the medical students at Sorbonne. There was a post vacant in mineralogy in 1902. He was refused for the second time. He was also refused the membership of the French academy of science. Paul Emile Appell, a well known French mathematician wished to see the name of Pierre Curie in the list of 'the Legion of Honour'. He wrote a letter to Marie :

'... I ask you to use all your influence to make sure Monsieur Curie does not refuse...'

Pierre readily replied 'I do not desire to be put on the list for decoration.'

In June 1903, Marie defended her doctoral thesis. And yes, in the same year, she got the Nobel Prize in Physics with her husband Pierre Curie and Henri Becquerel. Few nominators submitted the work of Rutherford & Soddy. Angstrom argued strongly, 'If some work be overtaken by other scientists, by no means diminish the honour for the first discovery of the phenomenon.' Marie Curie became the first woman to receive a Nobel Prize. She remained the first until her daughter Irene won the same prize in 1935. They were great scientists. They were great teachers also. Pierre wrote a letter to the Nobel Committee :

'We can not be gone from our classes at this time of year without incurring great difficulties in the teaching which is entrusted to us.' Simply unbelievable!

The announcement made a mixed reaction. Some people and press reminded us not to forget that she is a woman. In fact, 'Mrs. Curie is a devoted fellow laborer in her husband's research and has associated her name with his discoveries.' (New York Herald.)

Pierre Currie was introduced in the academy of sciences. He wrote his friend Georges Gouy :

'I find that I am in it without wanting to be and without the academy wanting to have me'. Madam was very joyful : 'Oh! me, I am only a woman'. Pierre was tried, for a second time, to confer the 'Legion of Honour'. Pierre replied, I do not feel the need of a decoration. I need a laboratory.'

In 1904, Pierre became professor of physics in Sorbonne. Pierre and Marie were provided with a large room there.

Both of them were suffering from radiation sickness. In 1906, Pierre was killed in a street accident. The professorship was offered to Marie and she became the first woman professor at Sorbonne. She continued to work on radium and isolation of polonium. In the meantime, there second daughter Eve was born on December 6,1904.

Marie as Leader of the Lab

There were seven workers in the laboratory at the time of expiry of Pierre Curie. Within three years, the number became twenty four. She got financial commitment from the University of Paris and Pasteur Institute to build a laboratory. She proved herself as a very able administrator. She was offered the 'Legion of Honour' but she refused. In 1910, she wanted to introduce her name in the French academy of sciences, a 215 years old Institute of France. Madam Curie was already a very prominent member of International Radium Standard Committee and also had her honourary membership from Swedish, Dutch, Czech and Polish academies. The clerical conservative group and the right wing press were opposing her membership and she got defeated by a vote of 60 to 85. For the next 11 years, she never requested anyone to present her paper in the academy. Irene, after receiving her Nobel Prize, also tried twice but was refused. Marguerite Percy, a doctoral student of Marie Curie (discoverer of Francium) became first woman member of the academy in 1962. She was working hard to make the 'Radium Institute' a reality.

Madam, for the first time in the world, got a second Nobel Prize in 1911 (in Chemistry) for the discovery of Radium and Polonium. She became seriously ill in 1911, was hospitalized and operated in March 1912.

World War I and Madame Curie

With a mobile X-ray vehicle, she treated the wounded soldiers in the battle field. She also donated her Nobel Medals for the cause of the war of the French people.

Madame as Institute Builder

Radium Institute was built in 1914. In 1925, she founded the Warsaw Radium Institute. She had also acted as head of the famous Pasteur Institute and a radioactivity laboratory in the University of Paris.

Her Last Days

She visited her motherland last in 1934. After few months, she breathed her last on 4th July 1934. In a sense, she sacrificed herself for the cause of science and human welfare. Her working laboratory is now transformed as 'Curie Museum'. Albert Einstein said, 'Marie Curie is, of all celebrated beings, the only one whom fame has not corrupted.'

This year is not only the 'International Year of Chemistry'. It has been declared as 'Year of Marie Curie' by two countries Poland and France. Element with atomic number '96' is known as 'Curium'. 'The Curie' (Ci) is the unit of radioactivity. Madame will be ever-remembered in our mind. How can one forget her immemorial words, 'I mostly think of what has to be done and not of what has been done.' She cautioned the future generation of scientists by saying, 'Science is essentially international, and it is only through lack of historical sense that national qualities have been attributed to it.'

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Girish Chandra Bose: A Pioneer in Indian Agriculture

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Abstract

In 1881 Girish Chandra Bose went to London on a Bengal Government scholarship for higher studies in agriculture. He believed that economic self-sufficiency was possible only through the development of agriculture. In 1886 he set up Bangabasi School for the dissemination and expansion of agricultural knowledge. Girish Chandra was a man of liberal and progressive views. The great contribution of Girish Chandra was in the field of education. According to him Indian agriculture is pre-eminently a petite culture and forms the backbone of the Indian village community of which the cultivator or ryot is the unit. The great problem of agriculture in India is the storing of water in the soil. Considering the soil, the climate, and the other conditions under which they have to work, the cattle are well adapted to the purposes of the ryot. It is true that there is never a dearth of wheat. For western India it is bajra or millet which sustains the entire belt of Gujarat, Maharashtra and Madhya Pradesh. The traditional wells and tank irrigation in India particularly in south and artesian wells in Rajasthan can be better means of rain harvesting and permanent solution to drought. To sustain agronomy, commercial agriculture has to be encouraged in area specific regions.

Girish Chandra Bose was born on 29th October, 1853, at the tiny village of Berugram in the district of Burdwan. From early boyhood, he showed a remarkable keenness and desire for knowledge which was greatly encouraged by his father Janaki Prasad Bose. Girish Chandra passed the Entrance Examination from the Hughli Branch School in 1870, FA and BA from the Hughli College in 1873 and 1876 respectively. After graduating, he joined Ravenshaw College, Cuttack as a lecturer of Botany. While teaching there, he obtained the MA degree in 1878.

In 1877 he married Nirad Mohini Devi, youngest daughter of Peary Charan Mitra of Burdwan. This marriage brought him in close contact with Pandit Iswar Chandra Vidyasagar.

In 1881 he went to London on a Bengal Government scholarship for higher studies in agriculture. In recognition of his extraordinary academic talent, he was made a life member of the Royal Agricultural Society in 1882 and was elected a Fellow of the Chemical Society of England in 1883. After completing his studies, Girish Chandra travelled to Scotland, France and Italy before returning home in 1884.

Girish Chandra believed that economic self-sufficiency was possible only through the development of agriculture. Within a year of his arrival in India from England, Girish Chandra started in April 1885 the first Indian Agricultural Journal which brought agricultural knowledge to the door of the masses. The weekly Journal was published in two languages, *Krishi Gazette* in Bengali and *Agricultural Gazette* in English. To this end he also wrote several books on botany and agriculture, among them *A Manual of Indian Botany*, *Bhu-tattva* (1882), *Krishi Darshan* (1st part, 1897), *Krishi Sopan* (1888), *Krishi Parichay* (1890), *Gachher Katha* (1910) and *Udbhid Jnan* (1923-25). *Bilater Patra* (1876) and *Europe Bhraman* (1884) narrate his European experience.

Girish Chandra had felt that an Agricultural journal can touch only a fringe of our greatest national problems; what was really needed was an institution on the model of Cirencester. He was among the first Indian stalwarts who had realized that the prosperity of our Motherland lay in the banishment of illiteracy and poverty. As a student in Cirencester, England he had studied in the minutest detail the American, British and Continental advancements in the twin domains of education and agriculture. He had gone to Cirencester not for securing a degree that would serve as a passport for a lucrative job for his personal gain. He had gone there to gather first hand knowledge of how a modern agricultural college worked for the benefit of the dumb millions, the poor and neglected sons of the soil. He had in his heart of hearts the keen desire to learn the technique of improving the economic condition of eighty per cent of our population who depend on agriculture. He had realised that in education constituted the strength of a nation.

In 1886 he set up Bangabasi School for the dissemination and expansion of agricultural knowledge. The idea of the institution originated with Principal Bose and the encouragement came from Pandit Iswar Chandra Vidyasagar. This was the first non-official and independent venture to establish an agricultural institution without any sort of Government aid or support. The school was upgraded into a college the next year. The patriot in Girish Chandra had taken upon himself a burden that was too heavy for the shoulders of an individual. The financial strain proved too heavy for him. The Agricultural Section of the Bangabasi School died out but its General Section was a success. It soon grew into a first grade College. Girish

Chandra was compelled under the circumstances to sacrifice the agricultural section, but in the general section he introduced the basic sciences of Botany and Chemistry that constituted the foundation of agricultural studies. Girish Chandra served the college as its Principal from 1887 to 1933 and in 1935 was nominated Rector.

Girish Chandra was a member of the University of Calcutta Senate and Syndicate. He was President of the Science Section of Bangiya Sahitya Sammelan (1919) and the founder president of the Botanical Society of Bengal (1935).

Girish Chandra was a man of liberal and progressive views. He did not believe in either caste-distinction or untouchability. He believed in work much more than in talk. He had a deep respect for women and stood for the spread of education among them. Girish Chandra was not an active participant in the nationalist movement, but his ardent patriotism and sense of national pride gave him a high place among the nationalists of the time. The great contribution of Girish Chandra was in the field of education. He thoroughly studied the educational system in foreign countries and believed in the dictum – 'from education and knowledge springs all power'.

Girish Chandra Bose died on 1st January, 1939.

Some instances of Girish Chandra Bose's writings from Pramatha Nath Bose's book:
"Indian rural economy is marked by two broad features which it is desirable at the outset to place clearly before our readers. First, it is no exaggeration to say that nearly the whole of the rural population lives by the cultivation of the soil, a statement which can hardly be made of any other country in the world. The famine Commissioners estimate that 90 per cent of the rural population lives more or less by agriculture. Secondly, Indian agriculture is pre-eminently a petite culture and forms the backbone of the Indian village community of which the cultivator or ryot is the unit. The village contains no doubt the blacksmith, the carpenter, the weaver, the potter and other handicraftsmen besides the ryot, but all alive for his benefit and are supported by the produce of his land. Take away the unit – the ryot the whole village organization breaks down. Various causes are now at work tending to draw the ryot from his land, to increase in fact the non-agricultural or landless class; but the love of the ryot for his small plot of land and homestead is so great that generations must yet elapse before this tendency will have any appreciable effect in disturbing the ancient rural organization of India. The ryot clings to his district with a tenacity which it is extremely difficult for an outsider to realize. Hence it is that the system of emigration devised by the Government with the best of intentions draw half-starved peasants from congested areas to sparsely populated ones, has not met with that amount of success which the system deserves."

Simplicity of Indian Agriculture

The systems of agriculture pursued in different parts of India vary infinitely in detail, but they all agree in one broad aspect, – simplicity. The implements of cultivation from the plough to the sickle are extremely simple in their construction and in the mode of their working; they are all manufactured, changed, and repaired in the village without any assistance from skilled town-mechanics. The motive power of the ryot, the inevitable bullock, supplemented here and there by the buffaloe, excepting in Sindh and the western districts of the Punjab where camels replace the bullock, is easy to manage, to breed, to feed, to doctor, and to buy and sell. The various operations of husbandry are equally simple. Ploughing in the English sense of turning up a furrow is unknown and perhaps unnecessary in this country, where it is a much simpler operation which turns up no furrow but merely scratches the surface soil, and requires no complicated implement like the English plough or skilled workman like the English plough-man. So on with the rest.

General Aspects of the Indian Agriculture

The great problem of agriculture in India is the storing of water in the soil. In this respect it differs totally from agriculture in Europe where the drainage of surplus water is the main difficulty. This essential requisite of Indian cultivation, except in localities where natural means are sufficient, is supplied by wells, as in the Punjab and the Decan, by tanks and *bandhs*, as in the Karnatic and the uplands of Bengal, by inundation channels as in Sindh and parts of Bihar, and by terraces cut on every hill side which together water a far larger area than is commanded by the Government canals and are more adapted to the soil, climate and social conditions of the people than the latter. But all these means of irrigation taken together do not command more than 13 per cent of the total cultivated area. In a country like India where rainfall is capricious, both in its amount and distribution, and where the conservation of water is the first and most essential requisite of cultivation, the proper control of the water-supply

becomes a question of paramount importance more so than the introduction of labour-saving implements, chemical manures and scientific methods of cultivation. Manures are copiously applied to his valuable crops by the ryot who knows fully well the forcing power of his applications; but his scope in this direction is limited both by the number of manures at his disposal and their quantity. Scientific agriculture can help him more in this than in any other department of his profession. Rotation of crops in its European sense is unknown and not at all a necessity in the vast rice-growing deltas of the great Indian rivers. But at the same time the exhausting effects of cropping a land with the same crop from year to year and the recuperative power of fallows are widely recognized. From the famous 'black' or 'cotton' soil of the Deccan, which is wonderfully fertile and retentive, and the alluvial soil of the river deltas, annually rejuvenated, to the deserts of Sindh and Rajputana, the soils present an infinite variety; and the ryot has adapted his cultivation to these varying conditions with a skill which only the accumulated experience of ages can generate in persons who follow a hereditary calling. The plough-cattle of India speaking generally are not such undersized, ungainly and inefficient creatures as foreigners have often described them. Considering the soil, the climate, and the other conditions under which they have to work, the cattle are well adapted to the purposes of the ryot. No doubt there are local breeds such as the Nellore cattle of Madras, the Amrit Mahal of Mysore and the trotting bullocks of Jubbulpore, which in point of breeding, beauty, and the special purposes for which they are bred can stand comparison with any cattle in the world. But even the much condemned ordinary plough-cattle of the country, if not carefully bred, are well looked after and well fed so far as the poor ryot's means allow. His means however, which are never very affluent, fall to their lowest ebb in seasons of scarcity; and his cattle have to share with him the pinch of penury and starvation which claim as victims thousands and thousands of their number annually. Add to this the heavy mortality due to various forms of cattle diseases which follow in the wake of scarcity, and the causes of the insufficiency and degeneracy of Indian cattle become apparent. Mr. Hume, a late Secretary to the Government of India in the Department of Revenue and Agriculture, estimates 'the average annual loss of cattle in India by preventable disease at 10 million beasts worth 7½ millions sterling.'

The author, Pramatha Nath Bose, states in the preface to his book: "I have also to gratefully acknowledge my obligations to Mr. G. C. Bose, M.A., M.R.A.C. for the chapter on agriculture".

Reviewing the book in the Calcutta Review, Romesh Chandra Dutt remarked: "We must hasten, however, to the Fourth Book, the last in these volumes, which contains interesting and valuable information about Agriculture and Industries. Mr. G. C. Bose, a specialist in Indian Agriculture, contributed the chapter on Agriculture, and it is in every way worthy of him."

Here an evaluation of his main arguments needs to be emphasized.

* An alarm for lack of food securities is sounded from time to time from colonial days based on rice economy alone. But Bose points out in his long article that food is not the only subsistence for India. It only applies to east and south. But in north India wheat has used to be the main serial. There is never a dearth of wheat. For western India it is bajra or millet which sustain the entire belt of Gujarat, Maharashtra and Madhya Pradesh. This kind of a mixed diet is habitual with Indians and can sustain the nation. This diversity has to be promoted by all means.

* Irrigation by river water through construction of huge dams or long grid of canals is not always satisfactory and is also expensive. The traditional wells and tank irrigation in India particularly in south and artesian wells in Rajasthan can be better means of rain harvesting and permanent solution to drought.

* To sustain agronomy, commercial agriculture has to be encouraged in area specific regions. Thus, jute for Bengal, tea for Assam, cotton for the Deccan, sugarcane and surplus wheat for Uttar Pradesh and Punjab should be especially encouraged through rotation of crops. These are traditional cash crops and need no special effort to promote them.

* He also thought that agro based industry should be promoted. But shall in tradition skill of the people in rural areas like pottery, basket making, mats, bell metal industries should be encouraged to fight seasonal unemployment.

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100 Years of Superconductivity

Part I

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Abstract

Superconductivity is a phenomenon of exactly zero electrical resistance occurring in certain materials below a characteristic temperature. It was discovered by Heike Kamerlingh Onnes in 1911 at Leiden in Netherland. Like ferromagnetism and atomic spectral lines, superconductivity is a quantum mechanical phenomenon in macroscopic scale. It is characterized by a) Zero resistance b) Persistent Current c) Perfect diamagnetism d) Flux quantization and e) Energy gap. Several unsuccessful attempts were made since early 1930s to explain the phenomena even by physicists like Bohr, Heisenberg and Feynman, until the Theory of Superconductivity was cracked by Bardeen, Cooper and Schrieffer in 1957 in the USA. In the meantime, important contributions towards understanding the superconductivity was made by Meissner & Öchsenfeld, London & London, Fröhlich, Maxwell, Reynolds and a group of Soviet physicists including Landau, Ginzburg, Abrikosov, Gorkov, Bogolyubov and others. In 1960s, another milestone, the Josephson Tunneling, was reached. Until recently, because of the cryogenic requirements of very low-temperature, superconductivity was merely an interesting topic occasionally discussed in physics classes. With the discovery of high - T_c superconductors, which can operate at liquid nitrogen temperatures (77 K), superconductivity is now well within the scope for practical applications. Even, high school students can explore and experiment with this new and important technological field of physics. The Part I of this two part article traces the bumpy ride towards the understanding of the theory of superconductivity from 1911 to about 1957. The second part will discuss the aftermath of BCS theory, Type II superconductors, Josephson Effect, high T_c superconductivity, recent developments and some applications.

Discovery

The story of superconductivity can be traced back to the early 19th century with scientists being able to liquefy gases. In 1823, Faraday discovered that gaseous chlorine could be liquefied by generating it at high pressure at one end of a sealed glass tube and cooling it at the other end. With a good understanding of the science behind the liquefaction, Faraday set out to liquefy every known gas. His method and instruments were crude: nevertheless, he succeeded in liquefying every known gas, with three exceptions: oxygen, nitrogen, and hydrogen. In 1877, French physicist Louis P. Cailletet and Swiss scientist Raoul P. Pictet independently succeeded in liquefying both oxygen and nitrogen. But their yield was very small. Before that achievement, many in the scientific community assumed that those gases, along with hydrogen, were perhaps beyond liquefaction. By 1883, Karol Olszewski and Zygmunt von Wroblewski in Cracow had succeeded in collecting cubic centimeters of liquid oxygen, and nitrogen. In 1892, Heike Kammerlingh Onnes, a young professor of Leiden University, succeeded in developing an apparatus for producing those in large quantities. The system took advantage of what became known as the cascade process. The only gas remaining to be conquered was hydrogen, as helium was unknown, although its existence in the Sun was known. The liquefaction of hydrogen developed into a bone of contention between Heike Kamerlingh Onnes and Sir James Dewar, the Scottish low-temperature physicist. In 1898, Dewar succeeded to liquefy hydrogen by taking advantage of a thermodynamic effect known as Joule-Thomson expansion.

Fig 1.Heike Kammerlingh Onnes

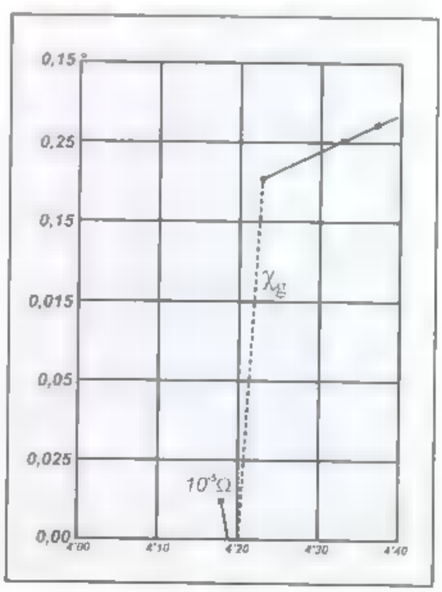

Fig 2. Kammerling Onnes' original plot of superconducting transition of Mercury.

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Losing the race for liquefying hydrogen to Dewar, Onnes developed the first helium liquefier in 1908. (Interestingly, Helium on the Earth was discovered only in 1895 by the English chemist William Ramsay). On July 10, 1908, he successfully liquefied helium by cooling it to 269 degrees below zero degrees Celsius (4 Kelvin or 4 K). The discovery opened the door to an entire realm of possibility involving low temperature experiments. This was the first successful attempt at liquefying helium which provided a new temperature range approaching absolute zero. Kamerlingh-Onnes pioneered work at very low temperatures just a few degrees above the absolute zero of temperature. He succeeded in reaching temperatures much colder than anyone before him and thus opened a new frontier for science, the field of low temperature physics. He and co-researchers Gilles Holst, a student entrusted by Onnes with precise resistance measurements, and G. J. Flim, the technician responsible for the helium liquefier itself, performed the experiments to study what happened to various properties of materials when they were extremely cold. Holst was studying the electrical resistance of wires. He found that as he cooled mercury wire, the electrical resistance of the wire took an abrupt drop when he got to about 3.6 degrees above absolute zero. The drop was enormous - the resistance became at least twenty thousand times smaller. The drop took place over a temperature interval too small for them to measure. As far as they could tell, the electrical resistance completely vanished.

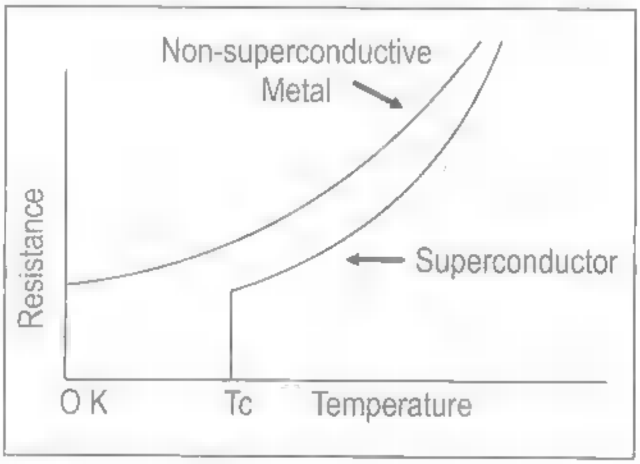

Fig 3. Low temperature plot of resistance versus temperature in Normal and Superconducting materials

Previous tests had found that the resistances fell exponentially as the temperature approached zero. It had been known for many years that the resistance of metals fell when cooled below room temperature, but it was not known what limiting value the resistance would approach, if the temperature were reduced to very close to 0 K. Some scientists, such as William Kelvin, believed that electrons flowing through a conductor would come to a complete halt as the temperature approached absolute zero. Other scientists, including Kamerlingh-Onnes, felt that a cold wire's resistance would dissipate. This suggested that there would be a steady decrease in electrical resistance, allowing for better conduction of electricity. At some very low temperature point, scientists felt that there would be a leveling off as the resistance reached some ill-defined minimum value allowing the current to flow with little or no resistance. However, the testing of mercury broke the notion. Onnes found that at 4.2 degrees Kelvin, the resistance of mercury fell sharply. Later Kamerlingh-Onnes described the phenomenon as:

"At this point (somewhat below 4.2 K) within some hundredths of a degree came a sudden fall not foreseen by the vibrator theory of resistance, that had been framed, bringing the resistance at once less than a millionth of its original value at the melting point... Mercury had passed into a new state, which on account of its extraordinary electrical properties may be called the superconductive state."

Fig (1) shows Onnes' original graph presented during his Nobel Lecture. To explain why resistivity depended on temperature at all, Onnes embraced Albert Einstein's recent theory of quantum oscillators, devised in 1906 to explain the observed specific heats of solids. If the thermal oscillations of atoms were what impeded the flow of current, and these oscillations became smaller at low temperature as Einstein would predict, then Einstein's oscillators might explain the way resistance diminished in metals at low temperature. This picture predicted that, rather than increase to infinity as the temperature approached 0K, the resistivity of a pure metal would fall toward zero. To test his idea, Onnes chose mercury, which could be purified by distillation, and which was expected to have a high enough resistance to measure at 4 K.

Repeated trials convinced Onnes that the sudden loss of mercury's resistance at about 4.2 K was real. The result was first presented by Onnes at the first Solvay Conference, held in Brussels from October 30th to November 3rd, 1911 under the title *"On the Sudden Change in the Rate at Which the Resistance of Mercury Disappears"*.He reported the work of his laboratory under his own name alone, without co-authors. Holst never got credit for discovering superconductivity.

Subsequent tests of tin and lead showed that superconductivity was a property of numerous metals if they were cooled sufficiently. Figure (2) is a graph of resistance versus temperature in normal as well as Superconducting materials.

By 1914 Onnes established a permanent current, or what he called a "persistent super current," in a superconducting coil of lead. The coil was placed in a cryostat at low temperature, with the current being induced by an external magnetic field. With no resistance, the electrons in the coil were free to continue to flow indefinitely. In one of Kamerlingh-Onnes experiments, he started a current flowing through a loop of lead wire cooled to 4 K. A year later the current was still flowing without significant current loss. Onnes noted that the state could be destroyed by applying a sufficiently large magnetic field while a current induced in a closed loop of superconducting wire persisted for an extraordinarily long time. He demonstrated the latter phenomenon by starting superconducting current in a coil in his Leiden laboratory and then transporting the coil plus the refrigerator, which kept it cold, to Cambridge University for a lecture demonstration on superconductivity. Physicists were making pilgrimages to Leiden to observe the inconceivable: a persistent current in a loop of superconducting wire, interacting with a common magnet needle.

Onnes's report did not cause much stir at that time, but Onnes recognized the importance of his discovery to the scientific community as well as its commercial potential. An electrical conductor with no resistance could carry current to any distance with no losses. In his Nobel Prize speech in 1913 (the prize was awarded for his researches on helium), Onnes underlined the unexpected, abrupt nature of the decrease in resistance. By 1913, it was established that the same phenomenon, now called "the super-conducting state," occurred in lead and tin, but not gold and platinum. In subsequent decades other superconducting metals, alloys and compounds were discovered. In 1941 niobium-nitride was found to super conduct at 16 K. In 1953 vanadium-silicon displayed superconductive properties at 17.5 K. And, in 1962 scientists at Westinghouse developed the first commercial superconducting wire, an alloy of niobium and titanium (NbTi). [Table 1 shows Superconducting Transition Temperature for some metals].

Metals	Transition temperature
Lead (Pb)	7.196 K
Lanthanum (La)	4.88 K
Tantalum (Ta)	4.47 K
Mercury (Hg)	4.15 K
Tin (Sn)	3.72 K
Indium (In)	3.41 K

Table 1: Superconducting Transition Temperature for some metals

Meissner Effect: The Next Revolution

Fig 4. Walther Meissner

The First World War brought a temporary break in low temperature research. Helium became unavailable in Europe. It restarted in 1919 with a gift of 30 cubic meter Helium coming from the USA. Helium was abundant in the United States. The Leiden group resumed work on superconductivity, discovering a number of new superconducting elements (thallium, indium, etc.), and also studying the magnetic properties of superconductors. In 1923 helium was liquefied in Toronto under J. C. McLennan. Two years later, in 1925, Walther Meissner in Berlin started liquid-helium research. He was eager to join Onnes' group in Leiden, but finally formed his own group. The research at Berlin was remarkable discovering whole new classes of superconducting elements, alloys and chemical compounds.

In 1933, Max von Laue, the German Nobel Laureate, suggested to Meissner an experiment designed to determine whether the current in a superconductor flows on its surface or in its bulk. Meissner chose Robert Ochsenfeld to carry out the experiment. To their surprise they found that a superconducting material repels a magnetic field and excludes it completely from its bulk. This means that if you bring a small bar magnet up to a superconductor, the superconductor bends the lines of force away from it and doesn't allow them to penetrate. This phenomenon is known as perfect diamagnetism and is today often referred to as the "Meissner effect" and is a very popular demonstration of superconductivity. The Meissner Effect is so strong that a magnet can actually be levitated.

over a superconductive material. The Meissner Effect will occur only if the magnetic field is relatively small. If the magnetic field becomes too great, it penetrates the interior of the metal and the metal loses its superconductivity. The magnetic field vanishes in the interior of a bulk specimen, even when cooled down below the transition temperature in the presence of a magnetic field. The diamagnetic currents which flow in a thin penetration layer near the surface of a simply connected body to shield the interior from an externally applied field are stable rather than metastable. On the other hand, persistent currents flowing in a multiply connected body, e.g., a loop, are metastable.

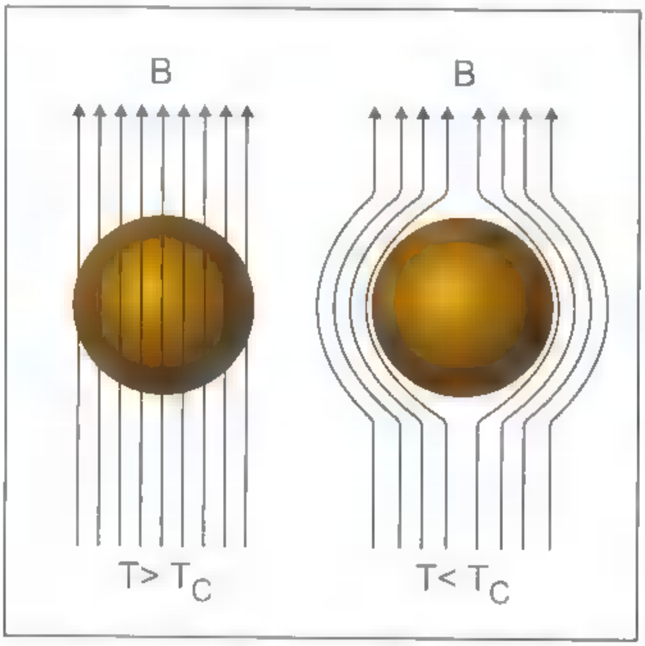

Fig 5: Diamagnetic property of a superconductor

An American, F. B. Silsbee, had suggested (using Leiden data), that the observed breakdown of superconductivity in a magnetic field was sufficient to explain why superconductivity was also destroyed when the sample carried a very large electric current: the current simply created the necessary magnetic field. The Leiden group verified Silsbee's hypothesis. They also developed the strong conviction that, when a sample became superconducting, whatever magnetic flux was already around became frozen in, and all other changes in flux through the sample would be excluded by the perfect conductivity. Thus the magnetic state of the sample was not reversible, so that no thermodynamic analysis could be applied. The result was dramatic and unexpected: even when the tin cylinders were not carrying any current, the magnetic field between them increased when they were cooled into their superconducting state. The frozen-in flux idea was not correct, and the exclusion of applied flux was not merely a dynamical effect of perfect conductivity. Superconductors were not only perfect conductors, they were also perfect diamagnets. Mathematically, we obtain a particularly useful form of this result if we limit ourselves to long thin specimens with long axis parallel to B_a ; now the demagnetizing field contribution to **B** will be negligible, whence:

$$\mathbf{B} = \mathbf{B}_a + 4\pi\mathbf{M} = 0 \quad \text{or} \quad \frac{M}{\mathbf{B}_a} = -\frac{1}{4\pi}$$

The result **B**=0 cannot be derived from the characterization of a superconductor as a medium of zero resistivity. From Ohm's law, **E**=ρ**j**, it can be easily shown that if the resistivity ρ goes zero while **j** finite, then **E** must be zero. By Maxwell's eqn. d**B**/dt is proportional to curl **E**, so that zero resistivityimplies d**B**/dt=0. This predicts that the flux through the metal cannot change on cooling through the transition. The Meissner effect contradicts this result and suggests that perfect diamagnetism is an essential property of the superconducting state.

Electrical & Magnetic Properties of Superconductors

Since there is no loss in electrical energy when superconductors carry electrical current, relatively narrow wires made of superconducting materials can be used to carry huge currents. However, there is a certain maximum current that these materials can be made to carry, above which they stop being superconductors. If too much current is pushed through a superconductor, it will revert to the normal state even though it may be below its transition temperature. The value of **Critical Current Density** (J_c) is a function of temperature; i.e., the colder you keep the superconductor the more current it can carry. For practical applications, J_c values in excess of 1000 amperes per square millimeter (A/mm) are preferred.

An electrical current in a wire creates a magnetic field around a wire. The strength of the magnetic field increases as the current in the wire increases. Because superconductors are able to carry large currents without loss of energy, they are well suited for making strong electromagnets. When a superconductor is cooled below its **transition temperature** (T_c) and a magnetic field is increased around it, the magnetic field remains around the superconductor. Physicists use the capital letter H as the symbol for **Magnetic Field**. If the magnetic field is increased to a given point the superconductor will go to the normal resistive state.

The maximum value for the magnetic field at a given temperature is known as the **Critical magnetic field** and is given the symbol H_c. For all superconductors there exists a region of temperatures and magnetic fields within which the material is superconducting. Outside this region the material is normal.

When the temperature is lowered to below the critical temperature,(T_c), the superconductor will "push" the field out of itself. It does this by creating surface currents in itself which produces a magnetic field exactly countering the external field, producing a "magnetic mirror". The superconductor becomes perfectly diamagnetic, canceling all magnetic flux in its interior. This perfect diamagnetic property of superconductors is perhaps the most fundamental macroscopic property of a superconductor. Flux exclusion due to what is referred to as the Meissner Effect, can be easily demonstrated in the classroom by lowering the temperature of the superconductor to below its T_c and placing a small magnet over it. The magnet will begin to float above the superconductor. In most cases the initial magnetic field from the magnet resting on the superconductor will be strong enough that some of the field will penetrate the material, resulting in a non-superconducting region. The magnet, therefore, will not levitate as high as one introduced after the superconductive state has been obtained.

Early Attempts Towards an Explanation

Before the discovery of the Meissner effect, attempts to make theoretical progress in explaining superconductivity, particularly by applying the newly created quantum theory, made little progress. In reality, there was no chance for anyone to solve this problem at the time of discovery because before one could explain it, one had to have the quantum theory in the form that Schrödinger and Heisenberg developed, which did not take place until the 1920's. For a long time the phenomenon of superconductivity was characterized by the statement that the electrical resistance vanished completely. Albert Einstein in 1922 concluded that quantum theory was not yet up to the task.

Fig 6. Fritz and Hans London

Between 1929 and 1933 Felix Bloch, whose doctoral thesis in 1928 gave the basic theory of conductivity in metals, worked on the problem together with Wolfgang Pauli and Lev Landau. Niels Bohr, Werner Heisenberg and Léon Brillouin also joined the efforts, but without any success.

The discovery of the Meissner Effect was a crucial turning point. Superconductivity still could not be explained in terms of quantum mechanics, but the thermodynamics of the phenomenon was understandable. Paul Ehrenfest, who believed that superconductivity could be treated as a thermodynamic phase transition, sent his former student Hendrik Casimir to Leiden, where in 1934 he joined Cornelius Gorter, a student of W. J. de Haas. The two of them succeeded in proving Ehrenfest correct, producing the results that are found today in every textbook. Casimir and Gorter advanced a two fluid model to account for the observed second order phase transition at T_c and other thermodynamic properties. They proposed that the total density of electrons ρ could be divided into two components $\rho = \rho_s + \rho_n$ where a fraction ρ_s/ρ_n of the electrons can be viewed as being condensed into a "superfluid," which is primarily responsible for the remarkable properties of superconductors, while the remaining electrons form an interpenetrating fluid of "normal" electrons. The fraction ρ_s/ρ_n grows steadily from zero at T_c to unity at $T = 0$, where "all of the electrons" are in the superfluid condensate.

A second important theoretical advance came in the following year, when brothers Fritz and Hans London, two refugees from Nazi Germany, at the Clarendon Laboratory at Oxford, proposed their phenomenological theory of the electromagnetic properties of superconductors, in which the diamagnetic rather than electric aspects were assumed to be more fundamental. In an ordinary metal we describe the phenomenon of electrical resistance by the famous Ohm's law. What the London brothers did was to show that there was another mathematical relationship which should be used in place of Ohm's law to describe superconductors. From this other relationship which they developed, they were able to explain both the Meissner-Ochsenfeld experiment as well as the persistent current of Kamerlingh-Onnes as two manifestations of the same thing.

They suggested that the electricalcurrent density **j**, carried by the superfluid is related to the electric field **E**

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and magnetic field **B** at each point in space by two London equations expressed in terms of measurable fields:

$$\frac{\partial \mathrm{j}_s}{\partial t} = \frac{n_s e^2}{m}\mathbf{E}, \qquad \nabla \times \mathrm{j}_s = -\frac{n_s e^2}{mc}\mathbf{B}.$$

Here $\mathbf{J}_s$ is the superconducting current, **E** and ■ are respectively the electric and magnetic fields within the superconductor, **e** is the charge of an electron & proton, m is electron mass, and $\mathbf{N}_s$ is a phenomenological constant loosely associated with a number density of superconducting careers.

The two equations can be combined to form a single "London Equation" in terms of the magnetic vector potential **A**:

$$\mathrm{j}_s = -\frac{n_s e^2}{mc}\mathbf{A}.$$

A is to be chosen such that $\nabla . \boldsymbol{A} = \mathbf{0}$ to ensure current conservation. If the second of London's equations is manipulated by applying Ampere's law

$$\nabla \times \mathrm{B} = \frac{4\pi \mathrm{j}}{c}$$

then the result is the differential equation

$$\nabla^2 \mathrm{B} = \frac{1}{\lambda^2}\mathrm{B}, \qquad \lambda = \sqrt{\frac{mc^2}{4\pi n_s e^2}}$$

Therefore, $\mathbf{B}(x) = \mathbf{B}_0 e^{-x/\lambda}$.

Thus, the London equations imply a characteristic length scale, λ, over which external magnetic fields are exponentially suppressed. This value is the London penetration depth. It follows that a magnetic field is excluded from a superconductor except within a distance which is of order of 10^{-6} cm in typical superconductors for T well below T_c. Observed values of λ are however several times the London value.

From London theory, the important phenomena of flux quantization can be easily understood. We consider here a superconducting ring. Deep in the interior of the superconductor, the magnetic field is completely screened out, and therefore, super currents should be absent there i.e.,

$$\oint j_s . \boldsymbol{dl} = 0$$

Introducing super current density and rearranging we get

$$\oint \boldsymbol{A}.d\boldsymbol{l} = \iint \boldsymbol{B}.d\boldsymbol{S} = \phi_s$$

is the magnetic flux through the ring. We see then, that the magnetic flux is quantized

$$\phi_s = \mathrm{n}\frac{2\pi hc}{e^*}\mathrm{n}\,\phi_0$$

in units of the flux quantum $\phi_0 = \frac{hc}{e^*}$

In the same year (1935) Fritz London suggested how the diamagnetic property might follow from quantum mechanics, if the wavefunction ψ of the superconducting state essentially remains unchanged by the presence of an externally applied magnetic field. This concept is basic to the theoretical development since that time, in that it sets the stage for the gap in the excitation spectrum of a superconductor which separates the energy of superfluid electrons from the energy of electrons in the normal fluid. Fritz London moved to USA in 1939 and in his book published in 1950, he extended his theoretical conjectures by suggesting that a superconductor is a *"quantum structure on a macroscopicscale [which is a] kind of solidification or condensation of the average momentum distribution"* of the electrons. This momentum space condensation locks the average momentum of each electron to a common value which extends over appreciable distance in space. London's book included very perceptive comments about the nature of the microscopic theory that have turned out to be remarkably accurate. He suggested that superconductivity requires "a kind of solidification or condensation of the average momentum distribution." He also predicted the phenomenon of flux quantization, which was not observed till 1960s or so. In 1940s David Schoenberg (the Russian-English Physicist at Cambridge) and John Bardeen in the USA also floated theories for explaining superconductivity but without any success.

Development Between 1950-57

The Second World War interrupted research in superconductivity just as the First World War had done. It was not until about 1950 that real progress began once again to be made. The phenomenon still resisted any true microscopic understanding, but some pieces of the puzzle did begin to come together, particularly in the phenomenological model of Vitaly Ginzburg and Lev Landau. Ginzburg and Landau (1950) extended the London phenomenology in a brilliant stroke based on Landau's theory of second-

order phase transitions. It does not purport to explain the microscopic mechanisms giving rise to superconductivity. Instead, it examines the macroscopic properties of a superconductor with the aid of general thermodynamic arguments. This theory is sometimes called phenomenological as it describes some of the phenomena of superconductivity without explaining the underlying microscopic mechanism. Based on Landau's previously-established theory of second-order phase transitions, Landau and Ginzburg argued that the free energy F of a superconductor near the superconducting transition can be expressed in terms of a complex order parameter ψ, which describes how deep into the superconducting phase the system is. The fee energy has the form where F_n is the free

$$F = F_n + \alpha|\psi|^2 + \frac{\beta}{2}|\psi|^4 + \frac{1}{2m}|(-ih\nabla - 2eA)\psi|^2 + \frac{|\mathbf{B}|^2}{2\mu_0}$$

energy in the normal phase, α and β are phenomenological parameters, m is an effective mass, e is the charge of an electron, **A** is the magnetic vector potential, and **B**=curl(**A**) is the magnetic field. By minimizing the free energy with respect to fluctuations in the order parameter and the vector potential, one arrives at the **Ginzburg–Landau equations**

$$\alpha\Psi + \beta|\Psi|^2\Psi + \frac{1}{2m}(-ih\nabla - 2eA)^2\Psi = 0$$

$$j = \frac{2e}{m}\mathrm{Re}\,\{\psi^*(-i\hbar\nabla - 2eA)\psi\}$$

where **j** denotes the electrical current density and *Re* the *real part*. The first equation, which bears interesting similarities to the time-independent Schrödinger equation, determines the order parameter ψ based on the applied magnetic field. The second equation then provides the superconducting current.This theory was later shown by Gor'kov (1959) to be a limiting case of the BCS theory and remains today as the standard initial approach to problems with a spatially varying superconducting state. The real significance of the wave function-like order parameter would not be explained until the microscopic BCS theory came along towards the end of the decade. However, even after the BCS theory provided a microscopic understanding of superconductivity, the much simpler and easier-to-use Ginzburg-Landau model remained (and remains) the every-day working theory used by theorists and experimentalists alike to analyze all manner of complex phenomena in superconductivity.

Fig 7. Vitaly Ginzburg (left) and Lev Landau

An important concept was introduced by A. B. Pippard in 1953. Aided by wartime development in high-frequency technology, Pippard was able to make very precise measurements of λ_L to compare with London Equation, using parameters determined from similar measurements of the skin depth in the normal state of metals. He found that, even at $T{\sim}0$, the fitted value of n_s was less than the density of conduction electrons in the normal state, by a ratio that was larger for low-T_c in materials like Al ($T_c \approx 1$ K) than for metals like Pb ($T_c \approx 7$ K). He concluded that a "coherence length" ξ_0 is associated with the superconducting state such that a perturbation of the superconductor at a point necessarily influences the superfluid within adistance ξ_0 of that point. For pure metals, $\xi_0{\sim}10^{-4}$ cm. for $T < T_c$. He generalized the London equation to a non-local form and accounted for thefact that the experimental value of the penetration depth is several times larger than the London value. Subsequently, Bardeen showed that Pippard's non-local relation would likely follow from an energy gap model.

Perhaps the single most important experiment which directly played a guiding role to an explanation of superconductivity was the experiment on the "isotope effect." This occurred in the spring of 1950. Papers from two laboratories simultaneously revealed the same results. One paper was by Reynolds, Serin, Wright and Nesbitt at Rutgers University. The other was by E. Maxwell at the U. S. National Bureau of Standards. Both groups measured the transition temperatures of separated mercury isotopes and found that in mercury T_c varies from 4.185K to 4.146K as the average atomic mass M varies from 199.5 to 203.4 a.m.u. The transition temperature changes smoothly as different isotopes of a same element mixed. This result behaves to the relation- $\mathbf{M^{\alpha}T_c = Constant}$.

Substance	α
Cd	0.32±0.07
Hg	0.50±0.03
Pb	0.49±0.02
Zn	0.45±0.05
Zr	*0.00±0.05*

Table 2. Observed values of α for isotope effect in superconductors

From the above relation and data between T_c and isotopic mass, we can understand that lattice vibration and electron-lattice interactions are closely related to superconductivity. So what the isotopic experiments we've just talked about showed was that although the electrical conductivity was known to arise because of the motion of the electrons, there's some role of these lattice vibrations. They enable the electrons suddenly to move through the lattice, evidently without hindrance, when the sample is cooled to the critical superconducting temperature.

It was the elementary discovery that transition temperature depends on number of nucleons. If the mass of the ions is important, their motion and thus the lattice vibrations must be involved. Independently, British physicist Herbert Fröhlich, who was then spending the spring term at Purdue University, attempted to develop a theory of superconductivity based on the self-energy of the electrons in the field of phonons. He heard about the isotope effect in mid-May, shortly before he submitted his paper for publication and was delighted to find very strong experimental confirmation of his ideas. He used a Hamiltonian, now called the Fröhlich Hamiltonian, in which interactions between electrons and phonons are included but Coulomb interactions are omitted except as they can be included in the energies of the individual electrons and phonons. Fröhlich used a perturbation theory approach and found instability of the Fermi surface if the electron-phonon interaction were sufficiently strong. Herbert Fröhlich realized that the observation that good conductors (copper, gold) tend not to become superconductors might mean that superconductivity is produced by a relatively strong interaction between the conduction electrons and the lattice vibrations, or phonons, in those metals that were not good normal conductors.

The next big experimental discovery was done by two groups: Goodman, who was making thermal conductivity experiments, and Brown, Zemansky and Boorse, who were making specific heat measurements. They discovered what is called the energy gap.

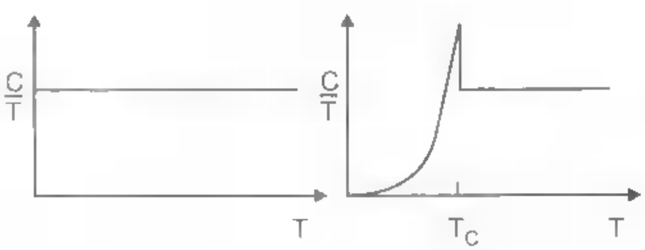

Fig 8. Temperature variation of electronic specific heat of normal metal (left) and superconductor

The specific heat of a solid C_v can be expressed as $C_v = \gamma T + \alpha T^3$, where the first term is the electronic contribution (predominant for good metals at very low temperature) and the second term is the lattice contribution. The graph above left shows the behavior of normal metal while that in the right shows the behavior in the superconducting state. The surprising feature of the curve is that below T_c the C_v falls as $e^{-\Delta/kT}$ indicating a clear gap in the electronic energy spectrum. The possible energy levels for electrons free to move about a volume V are found from the Schrödinger equation. The energy levels are quantized, and each level (ε) can be occupied by two fermions, one with spin up and one with spin down. At T = 0, the energy levels will be completely filled up to a certain energy, which is called the Fermi energy, ε_F. At T = 0, there will be no occupied states with $\varepsilon > \varepsilon_F$. In metals in normal state, electrons move above the Fermi Energy at T > 0 K. But in superconducting state this is not easy: you need to impart sufficiently more energy to overcome an energy gap above the Fermi Energy. It was a vital clue towards cracking the theory of superconductivity.

Thus by 1955-56, two indications were clear: the electron phonon interaction and energy gap. But a comprehensive theory was still eluding scientists. Meanwhile, Schafroth showed that starting with the Fröhlich Hamiltonian, one cannot derive the Meissner effect in any order of perturbation theory. Russian physicist Migdal's theory, supposedly correct to terms of order $(m/M)^{1/2}$, gave no gap or instability at the Fermi surface and no indication of superconductivity.

Bob Schrieffer summarized the situation as *"This was the state of our understanding of the electrodynamics of classic superconductors in the mid-1950s—a very satisfactory phenomenology, but no "explanation" in microscopic terms. What was the nature of the superconducting state that made it have these remarkable properties? This question was answered in one stroke by the classic paper of Bardeen, Cooper, and Schrieffer (1957) ..."*

Events Leading to the BCS Theory

The man who led the path breaking research leading to a satisfactory explanation to the phenomenon of superconductivity was John Bardeen. Bardeen recalls that *"My first introduction to superconductivity came in the 1930's and I greatly profited from reading David Shoenberg's little book on superconductivity, which gave an excellent summary of the experimental findings and of the phenomenological theories that had been developed"*. Bardeen's first abortive attempt to

construct a theory, in 1940, was strongly influenced by London's ideas and the key idea was small energy gaps at the Fermi surface arising from small lattice displacements. However, this work was interrupted by several years of wartime research. and then after the war Bardeen joined the group at the Bell Telephone Laboratories where his work turned to semiconductors. Bardeen came to University of Illinois at Urbanain the early 1950's as jointly a professor of physics and a professor of electrical engineering at the from Bell Laboratories where he, Walter Brattain, and William Shockley invented the transistor.It was not until then, as a result of the discovery of the isotope effect that Bardeen again began to become interested in Superconductivity. Bardeen heard about the isotope effect in early May, 1950 in a telephone call from Serin, and realized that the isotope effect identified the interaction between electrons and phonos that must be responsible for the phenomenon. The basic idea would be a Fermi-degenerate gas of nearly free electrons. with a weakly attractive interaction by way of the lattice phonons. he attempted to revive his earlier theory of energy gaps at the Fermi surface. with the gaps now arising from dynamic interactions with the phonons rather than from small static lattice displacements. Bardeen used a variational method rather than a perturbation approach but the theory was also based on the electron self-energy in the field of phonons. At the same time, Bardeen and Fröhlich independently put forward theories of superconductivity which later on turned out to be incorrect. It became evident that nearly all of the self-energy is included in the normal state and is little changed in the transition. A theory involving a true many-body interaction between the electrons seemed to be required to account for superconductivity. However, both of them said they thought an essential portion of the problem had to do with what happened to the electrons whose energy was equal to the Fermi energy. The interaction studied by Frohlich is at first sight quite appealing, being both novel and potentially involving the right dependence on the isotopic mass. There was however a major problem in understanding how it could play a role, since the basic Coulomb interaction between electrons is both repulsive and very much stronger. As Landau put it "*you can't repeal Coulomb's law.*"

In 1955, stimulated by writing a review article on the status of the theory of superconductivity, John Bardeen decided to renew the attack on the problem. Solving that problem proved to be a difficult task. There was also the threat of powerful competition. Richard Feynman, one of the masters of quantum electrodynamics, and renowned Soviet Physicists like Landau and Bogolyubov were close to the solution. In quantum electrodynamics, electrons in vacuum interact with one another via photons, or quantized light waves. In the model Bardeen was trying to solve, electrons in metals interact with one another via phonons, or quantized lattice vibrations. This was the problem which John Bardeen and David Pines, his post-doc fellow at the University of Illinois during the period 1952-55, attacked. What they found by extending an approach which David Bohm and David Pines had earlier developed for understanding the consequences of electron-electron interactions in metals, was that the medium is the message. When they took into account the influence of electronic screening processes on both electron-electron and electron-ion interactions, they found that the presence of a second component, the ions, makes possible a net attractive interaction between a pair of electrons whose energy difference is less than a characteristic phonon energy.

Fig 9. Bardeen (left), Cooper (center) and Schrieffer

In 1955, when Pines left University of Illinois, Bardeen decided that reinforcements were needed. He called up C. N. Yang at the Institute for Advanced Study at Princeton, to ask for a postdoc versed in the field theory. Yang recommended Leon Cooper since Cooper's background was in particle physics. Cooper had recently completed his PhD in particle physics and in the process he had learned a set of mathematical techniques called quantum field theory. He was viewed as one of the best young men in the subject. Bardeen felt it might be important to know these techniques in order to tackle the problem of superconductivity. So he

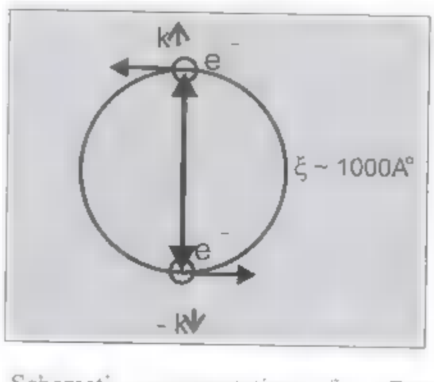

Fig. 10. Schematic representation of a Cooper Pair.

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invited Cooper to come to Urbana. Because of his mastery in quantum mechanics he was jokingly called by others in the department as *"Bardeen's quantum mechanic"*. Meanwhile, Bob Schrieffer was at the University of Illinois as a graduate student. He had completed his undergraduate studies at MIT, working in a group of solid state physicists. When he reached graduation time, he decided to work with Bardeen. Initially, Bardeen suggested some work on semiconductors. When it came time for a thesis, Schrieffer chose to work on superconductivity. The team was assembled at the University of Illinois physics department, Bardeen and Cooper had to share an office. In the meantime, Schrieffer worked in a room full of other graduate students. The situation was not conducive, but spirit of the trio was on high.

It soon became clear that since the existing field-theoretic methods were based on perturbation theory, another scheme would have to be devised. Bardeen stressed the importance of an energy gap in the excitation spectrum and that superconductivity is due to a condensation in momentum space of a coherent superposition of normal-state configurations. But it was difficult to explain quantitatively. Fortunately, Landau's theory of a Fermi liquid provided the necessary basis for treating the normal-state excitations in one-to-one correspondence with the free-electron gas so that the small condensation energy between the super and normal phases could be isolated.

The first major breakthrough this trio made in superconductivity came from Leon Cooper. Cooper was making an effort to find out why there was an

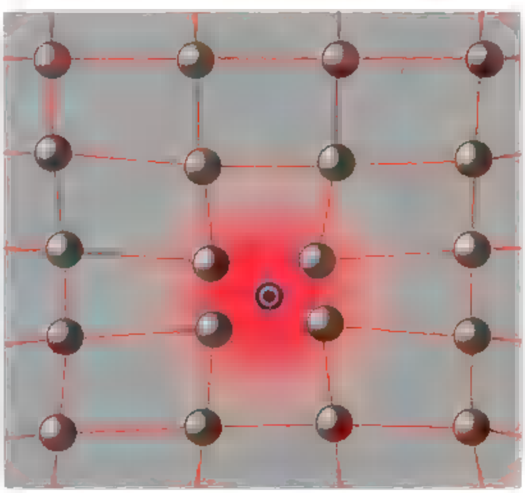

Fig 11. Electron Lattice interaction.

energy gap. Cooper studied the general theories of quantum mechanics and considered a simplified model of the interactions of two electrons. At very low temperature, all states up to Fermi level are filled and hence not available to these electrons. He then examined what considered : the first was that the Coulomb repulsion of electrons, because they are of the same charge. The second was that the electrons interact via lattice vibrations; one electron displaces a nucleus as it passes by the nucleus which in turn attracts another electron forming a pair of moving electrons. The interaction was energetically favorable - there was a net attraction.

Cooper concluded that superconductivity arose when the attractive interaction of one electron for the other, through the lattice, was larger than the direct repulsion.This then became a criterion for superconductivity. Cooper published a paper in 1956 and it is one of the famous papers in the history of superconductivity. The interacting pairs of electrons have since been known as "Cooper pairs" after their discoverer. It is interesting to note that in his 1956 paper, Cooper referred to Ginzburg and Scafrorth as saying that two electrons or even more, if grouped together and have zero or integral spin, would behave like Bosons.

At this point Bardeen, Cooper and Schrieffer decided to try to generalize Cooper's results to many electron systems. The trouble was that a Cooper Pair appeared to interact with a third or fourth electron unfavorably. They understood that a single Cooper pair was unstable. The break came when Bob Schrieffer succeeded in guessing the nature of the solution at absolute zero. They then attempted to generalize the solution to the higher temperatures, and to show that in fact they could account for all of the facts of superconductivity. The first joint paper of the groupwas published in February, 1957. This was the prelude to the final theory.

The trio then felt they were close to the success. But they still had lots to do. Bardeen went to Stockholm to collect his 1956 Nobel Prize while Cooper and Schrieffer engrossed into deep thinking and calculation. But within a few months they were successful. It became clear that the key to superconductivity is the condensation of all electron pairs into momentum space, that is, they will have same momentum (though they may be physically far apart) and can be described by a single wave function. It is easy to understand that such a situation may arise as the Cooper Pairs are Bosons and are not restricted by Pauli Exclusion Principle to occupy same energy states.

Their December 1957 paper (See Annexure I) successfully explained all aspects of Superconductivity. In 1972 John Bardeen, Leon Cooper and Bob Schrieffer were awarded the Nobel Prize in physics for their theory of superconductivity.

Salient Features of BCS Theory

- ♣ The electrons are bound into Cooper pairs, and these pairs form a Boson like condensate. In order to break a pair, one has to change energies of all other pairs. This means there is an "energy gap" for "single-particle excitation", unlike in the normal metal. This energy gap is highest at low temperatures but vanishes at the transition temperature when superconductivity ceases to exist.

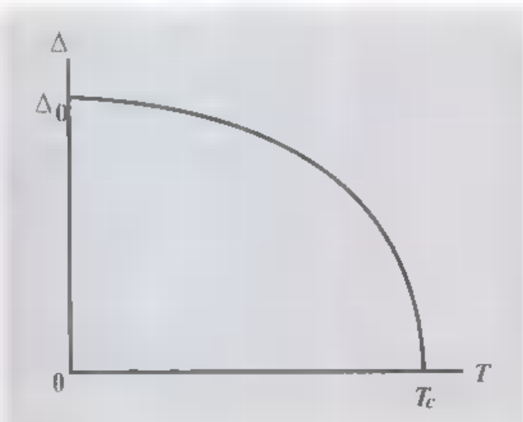

Fig 12. Variation of band gap with temperature.

- ♣ BCS theory predicts the dependence of the value of the energy gap, Δ at temperature T on the critical temperature Tc. The ratio between the value of the energy gap at zero temperature and the value of the superconducting transition temperature takes the universal value of 3.5, independent of material. Near the critical temperature the relation asymptotes to

$$E = 3.52\, k_B\, Tc \sqrt{1 - \left({}^{T}/_{T_c}\right)}$$

- ♣ Due to the energy gap, the specific heat of the superconductor is suppressed strongly at low temperatures, there being no thermal excitations left. However, before reaching the transition temperature, the specific heat of the superconductor becomes even higher than that of the normal conductor and the ratio of these two values is found to be universally given by 2.5.

$$C \sim \frac{\Delta^2}{T^2} \exp(-\beta/2\Delta)$$

- ♣ BCS theory correctly predicts the Meissner effect. It also describes the variation of the critical magnetic field with temperature. In its simplest form, BCS gives the superconducting transition temperature in terms of the electron-phonon coupling potential and the Debye cutoff energy:

$$k_B T_c = \beta_c^{-1} \approx 1.13\, \hbar\omega_D \exp(-1/N(0)\,\lambda)$$

Here N (0) is the electronic density of states at the Fermi energy. This shows that $Tc \sim \omega_D \sim M^{-1/2}$ explaining the isotopic effect.

[It being very complicated and not suitable for this paper, the author decides to avoid discussing the detail mathematics of BCS Theory. However, it must be kept in mind that important mathematical tools had been developed by several physicists who made the BCS calculation possible. One can find Bardeen's acknowledgement from his 1972 Nobel Lecture:
"In 1950, diagrammatic methods were just being introduced into quantum field theory to account for the interaction of electrons with the field of photons. It was several years before they were developed with full power for application to the quantum statistical mechanics of many interacting particles. Following Matsubara, those prominent in the development of the theoretical methods include Kubo, Martin and Schwinger, and particularly the Soviet physicists, Migdal, Galitski, Abrikosov, Dzyaloshinski, and Gor'kov. The methods were first introduced to superconductivity theory by Gor'kov and a little later in a somewhat different form by Kadanoff and Martin. Problems of superconductivity have provided many applications for the powerful Green's function methods of many-body theory and these applications have helped to further develop the theory. Diagrammatic methods were first applied to discuss electron-phonon interactions in normal metals by Migdal and his method was extended to superconductors by Eliashberg. A similar approach was given by Nambu. The theories are accurate to terms of order $(m/M)^{1/2}$ where m is the mass of the electron and M the mass of the ion, and so give quite accurate quantitative accounts of the properties of both normal metals and super-conductors."]

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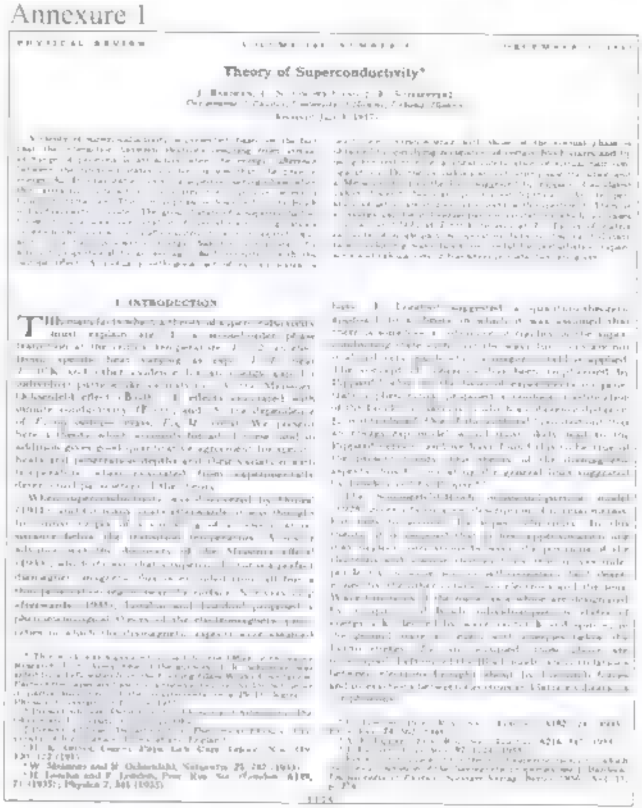
Annexure 1


PHYSICAL REVIEW

Theory of Superconductivity*

I. INTRODUCTION

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VOLUME 3, NO. 1, JANUARY, 2012

Social Insects Shaping Our Future

Subha Sankar Ghosh

Abstract

Social insects like ants, bees, wasps are mysterious creatures for the complex society they build. Inspite of their anatomical simplicity, they have survived and almost dominated Earth for some 130 million years. Recent researches on their behavior has inspired the development of some novel computer programs which promise to solve some of the very complicated problems of the modern society.

Introduction

Social insects like ants, termites, many bees, and some wasps have a real family life which is very complex. They live in communities, and the members of a community depend on one another. Interestingly their body organization is very simple with a very primitive brain. They arrived on Earth in the Mid Cretaceous period at around 110 to 130 million years ago and are still thriving without much difficulty[1]. Infact there are around 22,000 species of ants, 20,000 species of bees and more than 100,000 species of Wasps. The wide diversity of these social insects is a testimony to their success. But why are they so successful?

Researches on social insects like ants and bees have revealed that they have a very meager intelligence. But their colonies can solve problems unthinkable for an individual insect, such as finding the shortest path to the best food source, allocating workers to different tasks, or defending a territory from neighbours[2]. Interestingly an average colony of ants has more than a lakh ant. Yet no one is in chargé of the colony. The famous "queen" ant has no role but to act as a breeder. Rest members alter their duties according to the requirement.

Scientists believe that the preponderance of these groups of insects is because of the three qualities that they are endowed with-

a) Ability to adapt to the changing environment.
b) Robustness i.e.; performing the task even if some individuals of the colony fails.
c) Ability to self organize, independent of any centralized control. The underlying factor that controls this unique action is called *'Stigmergy'* or self communication through environment.

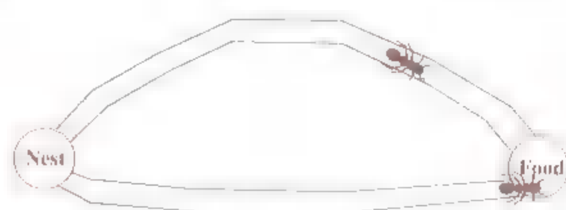
Social Insects and Our Future

New findings on the behavior of ants and honeybees are giving surprising results which can even be applied to solve complicated problems of the modern society. Taking cue from these findings, MNC giants like Southwest Airlines, Unilever, Mcgraw Hill, Hewitt Packard have tried to implement them in their organizations. According to them, these principles have not only helped them to run their operations more efficiently, but also to save millions of dollars annually. Such is the impact of these new findings that experts predict that the social insects' intelligence is going to shape our lives and make it better in the days to come.

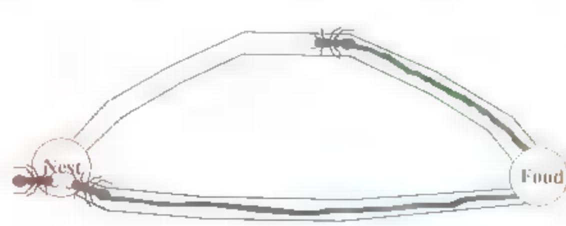
As such it will be pertinent to go through some of the findings that have been observed in these insects which can revolutionize our lives.

Ability to Find the Shortest Path from the Food Source to the Nest

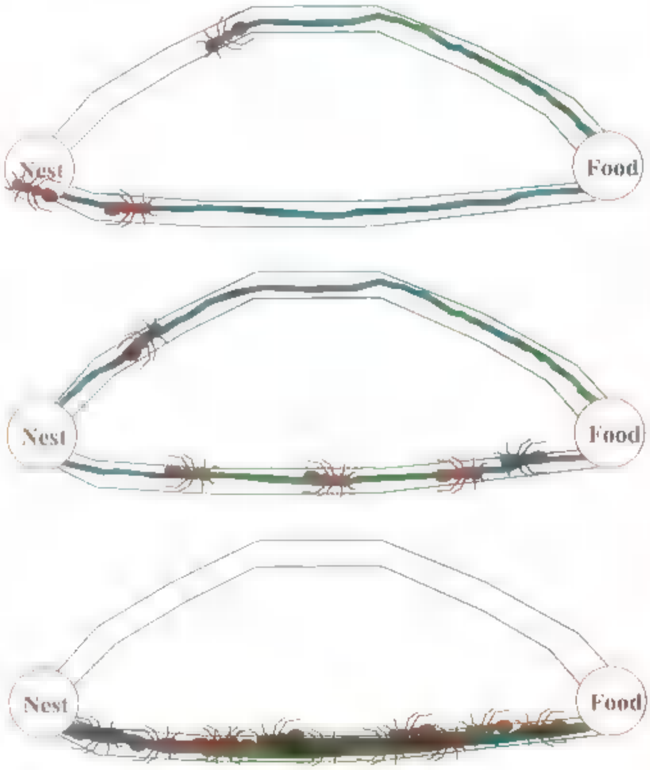
It has been observed experimentally that ants chose the shortest path to reach the food from the nest, even though there may be more than one path[4].



Scientists predict that this can only be possible by the application of the principle of self organization. Ants form and maintain a line to their food source by laying a trail of pheromone, i.e. a chemical to which can be sensed by other members of the same species. They deposit a certain amount of pheromone while walking, and each ant prefers to follow a direction rich in



pheromone. This enables the ant colony to quickly find the shortest route. The first ants to return should normally be those on the shortest route, so this will be the first to be doubly marked by pheromone (once in each direction). Thus other ants will be more attracted to this route than to longer ones not yet doubly marked, which means it will become even more strongly marked with pheromone. Soon nearly all the ants will choose this route. The volatility of the pheromone assures that no trail remains on the route which is longer and as such no ant will chose that route.



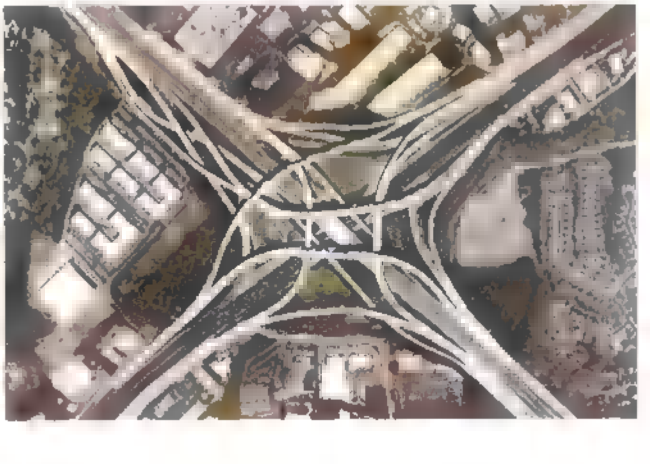
Software based on this new routing algorithm is popularly known as *'AntNet'*. In the AntNet algorithm, routing is determined by means of very complex interactions of forward and backward network exploration agents ("ants"). The idea behind this sub-division of agents is to allow the backward ants to utilize the useful information gathered by the forward ants on their trip from source to destination. 'AntNet', exhibits a number of interesting properties: it works in a fully distributed way, is highly adaptive to network and traffic changes, uses lightweight mobile agents (called ants) for active path sampling, is robust to agent failures, provides multipath routing, and automatically takes care of data load spreading. 'AntNet's performance has been extensively tested in simulation, considering different networks and traffic patterns, and has been compared to several state-of-the-art routing algorithms. Interestingly 'AntNet' has largely outperformed all its competitors, showing excellent adaptivity and robustness. 'AntNet' has been also tested in small physical networks, confirming the good performance in real-world tests[5].

Congestion Free Telecommunication

The unique feature of the pheromone and the associated ant behavior has inspired researchers from the telecom wing of Hewitt Packard to develop a modified computer program called ***Ant - Based Control*** **(ABC)**, that works on the similar principle as AntNet. In this program, only one class of ants are launched from the sources to various destinations at regular time interval which get destroyed on reaching the node. The quickest to be destroyed represents the uncongested route. Once a successful search is made, the information is then deposited in the nodes via digital pheromones which then influence the subsequent behavior that is related to the task. In due course of time, the behavior get temporarily stored that may be used again in future, if the need arise. Reinforcement by similar agents about an uncongested path attracts the phone calls to follow the trail and pass through the uncongested route. Conversely when this path gets congested, the path is abandoned by lesser reinforcement and a new uncongested path is discovered by the agents. As a result a congestion free telecommunication system could be developed, even when the traffic is high. Encouraged by the results, other MNC's like British Telecom, MCI World Com, France Telecom have started implementing the program in their telecommunication network.

No Traffic Jam

A modified version of 'AntNet' software has been done for dynamic routing of traffic in a city where in a simulated environment vehicles are guided through different roads based on the load of traffic. In order to streamline the process, artificial ants are created which



move in a virtual street network. This model is supplemented with actual data from the traffic by the cars themselves through the use of satellite navigation. This enables the agents (artificial ants) to divert the traffic from congested routes and improves the traveling time. The simulation environment makes it possible to see the effect in different cities or in accident or emergency circumstances, where because of a disaster, multiple roads become unavailable or are heavily congested, and most of the drivers are get confused.

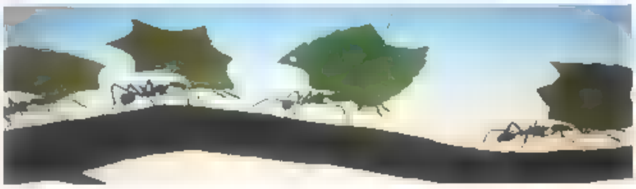
Extension of the above program can be applied even for air trafficking. Southwest Airlines, a leading airline in USA, has already implemented this technology to solve its cargo handling problem and have gained more than 10 million dollars in a single year.

Current research in this field have shown that the above system could be used for Wireless communication network and even for guiding unmanned military robots in warfare.

Flexibility in Task Allocation

Contrary to the popular notion, a lot of flexibility has been found among these insects. For instance, an ant may perform several kinds of job. When the colony discovers a new food source, an ant which was doing housekeeping duty may suddenly become a forager. Or if the colony's territory size expands or contracts, patroller ants change the nature of their scrutiny pattern. Similar kind of behavior can be seen in case of Honeybees where the nurse bees can even go for foraging if the situation demands so.

This principle has been the inspiration behind the development of software programs that will allow for switching between a set of activities, if needed.



Similarly, when the ant carries food to the nest, they follow a relay mechanism. Interestingly the distance up to which a single ant will carry the food is not fixed. This seemingly simple activity has encouraged Human Resource managers of companies like McGraw-Hill, Blockbuster Music etc. to dismantle the zone division concept in their factory line production process. Moreover keeping in mind the differential ability of the workers, it has been found that allotting the best and the fastest workers at the end of the chain process have increased the overall productivity by 30%.

No Top Down Approach, Only Best Idea Flourish

As has been already mentioned, there are no supervisors in the society of social insects. It has been found in bees that they make decisions by seeking a diversity of options that has been presented by scout bees through their waggle dance. Then a free competition among different options is weighed and finally an effective mechanism is devised to narrow down the choices to choose the best option.

Similar kind of management skill has been applied in a major credit card company called Capital One where every member has been empowered to give a good idea, irrespective of the hierarchy. Once any idea comes forth, it is analyzed thoroughly and necessary addendum is made by experts, if required, before implementation. To make this system more effective, some companies are encouraging their employees to post their ideas online where everyone can study it. The idea that gets the highest number of votes is taken up. In return the originator of the idea is suitably rewarded.

Though this approach does not match with the conventional management practice, but the approach has already started showing some very encouraging results. Scientists have found that these insects' approach towards exploiting a new food source vary from one species to another and the underlying reasons, if deciphered properly, may give valuable lessons to the managers regarding potential market exploitation.

Conclusion

Swarm intelligence boasts a number of advantages due to the use of mobile agents and stigmergy. These are:

1. Scalability: Population of the agents can be adapted according to the network size.
2. Fault tolerance: Swarm intelligent processes do not rely on a centralized control mechanism. Therefore the loss of a few nodes or links does not result in catastrophic failure, but rather leads to graceful, scalable degradation.
3. Adaptation: Agents can change, die or reproduce, according to network changes.
4. Speed: Changes in the network can be propagated very fast.
5. Modularity: Agents act independently of other network layers.
6. Autonomy: Little or no human supervision is required.
7. Parallelism: Agent's operations are inherently parallel.

Notwithstanding the number of interesting applications presented, a number of open problems need to be addressed and solved before that of ant algorithms becomes a mature field. For example, it would be interesting to give an answer to the following questions:

How do we define "artificial ants"? How complex should they be? Should they all be identical? What basic capabilities should they be given? Should they be able to learn? Should they be purely reactive? How local should their environment knowledge be? Should they be able to communicate directly? If yes, what type of information should they communicate?

Even though the field of Ant based algorithms is in its nascent stage, yet researchers predict that as more studies are conducted on these insects, we may get some unthinkable results that may change our outlook and our future lives. Perhaps these insects remind us of the old proverb: "Nature is the best teacher".

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Designing an Automated System for Medical Diagnosis

Ranjan Parekh

Abstract

This paper proposes an automated system for recognizing disease conditions of human skin in context to health informatics. Skin texture images, displaying three dermatological skin conditions, are analyzed using a texture analysis technique, based on a set of normalized symmetrical Grey Level Co-occurrence Matrices (GLCM), and features are extracted from them using automated algorithms. The features are fed to neural network classifiers for identification of the disease type. The features are considered in various combinations viz. individually, in joint 2-D and 3-D feature spaces, to find out the best recognition accuracies.

Keywords

Medical image analysis, texture recognition, grey level co-occurrence matrix (GLCM), neural networks, computer vision.

1. Introduction

In recent years, computer vision methodologies have been applied to the fields of health informatics and telemedicine for automated diagnosis of diseases. Interest in automated health diagnosis has been triggered by the huge collection of medical images generated everyday all over the world. For example, the Radiology Department of the University Hospital of Geneva alone produces more than 12,000 images a day [Muller, 2004]. Automated diagnosis measures have shown great potentials for reducing diagnostic errors and improving the accuracy and efficiency of medical diagnosis. Diagnostic errors have huge negative impact on patient care, such as an incremental cost per patient and increase in hospital stay as reported in a Harvard study [Bates, 1997]. In the United States alone, medical error results in 44,000-98,000 unnecessary deaths each year and 1,000,000 excess injuries [Weingart, 2000]. Ironically, most diagnostic errors are preventable. Research shows that diagnosis errors often occur when clinicians are inexperienced and new procedures are introduced. Further, age, complex care, urgent care, and prolonged hospital stay have been found to be correlated with diagnostic errors. Application of automated information systems in medical analysis has shown great promise in reducing such errors [Copec, 2003]

Automated diagnostic systems based on medical imaging, work by using image processing techniques to recognize and differentiate disease characteristics from digital images. Two important steps are used : (1) Visual features are extracted from the images and represented using a mathematical data model (2) the data representation is then fed to a statistical classifier like a neural network, for identification and classification of the disease.

Image features usually involve the following either individually or in various combinations : color, texture, shape. In this paper we focus on using texture as a means of identifying skin diseases from medical images using an automated procedure. Texture refers to visual patterns for describing the variation of color or grey tones over the image. The choice of the features, depend on what characteristics we are trying to identify from the image that best describes the diseases in question. In many cases computer system designers need to take help from medical professionals to isolate the best set of features most useful in describing a specific disease condition. The organization of the paper is as follows : section 2 provides an overview of the related work, section 3 outlines the proposed approaches with discussions on overview, feature computation and classification schemes, section 4 provides details of the dataset and experimental results obtained, section 5 provides an analysis of the current work vis-à-vis other related works, and section 6 provides the overall conclusion and scope for further research.

2. Related Works

Many methodologies have been proposed to analyze and recognize textures and shapes in an automated fashion. One of the first studies involved derivation of texture energy measures using a set of simple masks (vertical, horizontal, diagonal and anti-diagonal) [Wang, 1986]. Authors like Tamura [Tamura, 1978] made an attempt at defining a set of visually relevant texture features. This includes coarseness, contrast, directionality, line-likeness, regularity, roughness. Pentland [Pentland, 1984] reports a high degree of correlation between fractal dimensions and human estimates of roughness. Two-state Markov models have been used to detect texture edges characterized by changes in first order statistics [Huang, 1984]. Gabor filters have been used in several image analysis applications including texture classification and segmentation [Bovik, 1990].

Specifically, computer vision techniques involving texture analysis have been applied to health informatics to predict and characterize skin diseases. N. K. Al abbadi et al. [Alabbadi, 2008] have proposed a method for skin texture recognition using a 3 layer neural network using both skin color and texture features. In [Rubegni, 2002] authors propose a method of diagnosis of pigmented skin lesions by using a digital dermoscopy analyzer to evaluate a series of clinically atypical, flat pigmented skin lesions. Fractal parameters such as lacunarity and fractal dimensions have been used in diagnosis of skin cancers [Blackledge, 2009]. The use of Bayesian networks for skin texture recognition has been reported in [Shahreza, 2008]. A review of image analysis techniques for medical diagnosis can be found in [Muller, 2004].

3. Proposed Approach

3.1 GLCM : An Overview

This section describes how a popular texture modeling technique called Grey Level Co-occurrence Matrix (GLCM) can be used to model texture content in images. A GLCM [Haralick, 1979] indicates probability of a grey-level i occurring in the neighbourhood of grey-level j at a distance d and direction θ.

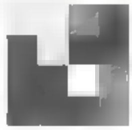
$$G=P(i,j|d,\theta) \qquad (1)$$

GLCMs can be computed from texture images using different values of d and θ and these probability values create the co-occurrence matrix. Consider a 4 by 4 section **I** of an image having four grey-level intensities as shown below.

$$\mathbf{I}=\begin{bmatrix}0&0&1&1\\0&0&1&1\\0&2&2&2\\2&2&3&3\end{bmatrix}$$

To compute the frequency of one grey tone in the neighbourhood of others, a 4 × 4 matrix is formed (since there are four distinct grey tones) and sequential numbers along the left (reference) and top (neighbour) are used to indicate them. The frequencies in which each pair (reference-neighbour) of grey-tones, occur together in **I** is now computed i.e. for a reference grey-tone i, how many times the neighbour grey-tone j occurs near it within **I**, and this constitutes the (i,j)-th element of GLCM matrix G. For simplicity's sake we consider the distance d as 1 i.e. only adjacent pixels are considered, and angle θ as 0° i.e. along the positive x-axis from left to right.

$$\mathbf{G}=\begin{array}{c|cccc} & 0 & 1 & 2 & 3\\ \hline 0 & 2 & 2 & 1 & 0\\ 1 & 0 & 2 & 0 & 0\\ 2 & 0 & 0 & 3 & 1\\ 3 & 0 & 0 & 0 & 1\end{array}$$



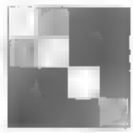
For example, 0 (reference) adjacent to 0 (neighbour) in **I** occurs 2 times (rows 1 and 2), hence we put 2 at position (0,0) of **G**, 0 adjacent to 1 occurs 2 times (rows 1 and 2) hence (0,1) contains 2, 0 adjacent to 2 occurs 1 time (row 3) hence (0,2) contains 1 and so on. This procedure is repeated for all pairs of intensities.

If we had moved along the ve x-axis, i.e. we had looked from right to left, then the matrix formed would have been the transpose matrix $\mathbf{G}^T$. To make the matrix independent of this factor, the transpose is added to the original to make it symmetrical viz. $\mathbf{S}=\mathbf{G}+\mathbf{G}^T$:

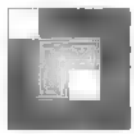
$$\mathbf{G}+\mathbf{G}^T=\begin{bmatrix}2&2&1&0\\0&2&0&0\\0&0&3&1\\0&0&0&1\end{bmatrix}+\begin{bmatrix}2&0&0&0\\2&2&0&0\\1&0&3&0\\0&0&1&1\end{bmatrix}=\begin{bmatrix}4&2&1&0\\2&4&0&0\\1&0&6&1\\0&0&1&2\end{bmatrix}=\mathbf{S}$$

The symmetrical GLCM is finally normalized by dividing each element by the sum of all elements to form $\mathbf{S}_0$. The '0' in the subscript indicates angle $\theta = 0°$. Directional GLCMs can also be computed along three other directions: vertical (θ = 90°), right diagonal (θ = 45°) and left diagonal (θ = 135°) generating matrices $\mathbf{S}_{45}$, $\mathbf{S}_{90}$, and $\mathbf{S}_{135}$:

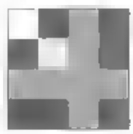
$$\mathbf{S}_0=\frac{1}{24}\begin{bmatrix}4&2&1&0\\2&4&0&0\\1&0&6&1\\0&0&1&2\end{bmatrix}$$



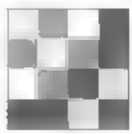
$$\mathbf{S}_{45}=\frac{1}{18}\begin{bmatrix}4&1&0&0\\1&2&2&0\\0&2&4&1\\0&0&1&0\end{bmatrix}$$



$$\mathbf{S}_{90}=\frac{1}{24}\begin{bmatrix}6&0&2&0\\0&4&2&0\\2&2&2&2\\0&0&2&0\end{bmatrix}$$



$$\mathbf{S}_{135}=\frac{1}{18}\begin{bmatrix}2&1&3&0\\1&2&1&0\\3&1&0&2\\0&0&2&0\end{bmatrix}$$



3.2 GLCM based Features

An 8-bit grayscale image typically contains 256 different grey tones which generates GLCMs having

256 by 256 elements. Since it is inconvenient to deal with such large matrices, a set of scalar features are usually derived from directional normalized symmetrical GLCMs and used for texture characterization viz. GLCM Contrast ©, GLCM Homogeneity (H), GLCM Mean (M), GLCM Variance (V) and GLCM Energy (N) as defined in Eq. (2). Here Si,j represents the element (i,j) of a normalized symmetrical GLCM, and k the number of grey levels.

$$C = \sum_{i=1}^{k} \sum_{j=1}^{k} S_{i,j}(i-j)^2$$

$$H = \sum_{i=1}^{k} \sum_{j=1}^{k} \frac{S_{i,j}}{1+(i-j)^2}$$

$$M = M_i = \sum_{i=1}^{k} \sum_{j=1}^{k} iS_{i,j} = M_j = \sum_{i=1}^{k} \sum_{j=1}^{k} jS_{i,j} \qquad (2)$$

$$V = \sum_{i=1}^{k} \sum_{j=1}^{k} S_{i,j}(i-M_i)^2 = \sum_{i=1}^{k} \sum_{j=1}^{k}$$

$$N = \sqrt{\sum_{i=1}^{k} \sum_{j=1}^{k} S^2_{i,j}}$$

3.3 GLCM based Classification

A texture class i consists of a set of n member images: $T_i\{t_1,t_2,...t_n\}_i$. For each member image, four directional symmetrical normalized GLCMs are computed as indicated below :

$\{(t_0, t_{45}, t_{90}, t_{135})\}_1, ..., (t_0, t_{45}, t_{90}, t_{135})_n\}_i$

For each directional GLCM, features in Eq. (2) are computed. Each feature is averaged over the four directional GLCMs, for each member image viz.

$\{(\bar{t}_x)_1, ..., (\bar{t}_x)_n\}_i$

where, $t_{\bar{x}} = \frac{t_{x,0}+t_{x,45}+t_{x,90}+t_{x,135}}{4}$ and $X \in \{C, H, M, N, V\}$. A texture class is characterized by the collection of its feature values obtained during a training phase. A test image S_j with its computed average features $(S_{\bar{x}})_j$ is said to belong to a specific texture class if the probability of its feature values being a member of that training class is maximum. To compute class probability neural network classifiers (multi-layer perceptron : MLP) using feed-forward back-propagation architectures are employed in this work.

3.4 Neural Networks : An Overview

Artificial neural networks are a set of algorithms meant to simulate workings of human nerve cells or neurons. A neuron receives input stimuli from a number of sources using an electro-chemical process and produces a response ('fires') when concentration of electrical charges exceeds a certain threshold. An artificial neural unit is also visualized as a structure having n inputs, and each input channel i can carry a signal xi. The neural unit can produce an output o when the sum of the input signals exceeds a certain pre-defined threshold θ i.e. when $x_1+x_2+...+x_n \geq \theta$. See Fig. 1.

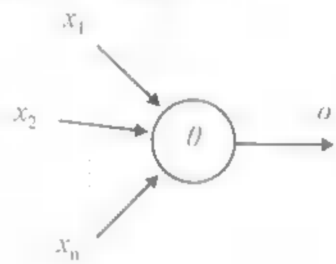


Fig. 1. Artificial neuron unit

One of the earliest neurons is the McCulloh- Pitts neuron where the inputs and outputs are considered as binary values. Fig. 2 shows simple implementations of 'AND' and 'OR' logical gates using McCulloh-Pitts neurons having thresholds of 2 and 1 respectively.

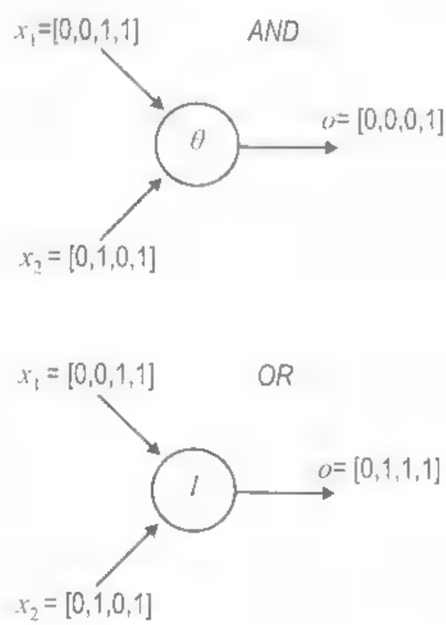


Fig. 2. Using McCulloh-Pitts neurons to implement AND and OR logical gates

The perceptron was proposed as a more generalized model of the McCulloh-Pitts neuron and is nowadays extensively used in classification problems in various domains. The essential difference is the presence of numerical weights associated with input lines. See Fig. 3. This imparts the perceptron the capability to *learn* by adapting the weights to suit a particular classification problem. The input signals and weights are now no longer restricted to binary values but can take on any real value. The input signals are designated by an input vector $X=\{x_1, x_2, ..., x_n\}$ and the weights by a weight vector $W=\{w_1, w_2, ..., w_n\}$. The perceptron also has a bias line connected to a bias signal (B) kept permanently 1 and an associated bias weight (b). The net input N to the perceptron is given by :

$$N=b+W.X^T=b+\sum_{i}^{n} w_i x_i \qquad (3)$$

The output O produced by the perceptron is no longer determined by a threshold value but by a transfer function f. In most cases the transfer function is of the log-sigmoid or the tan-sigmoid forms depicted below :

$$O=f(N)=\frac{1}{1+e^{-N}} \qquad (4)$$

$$O=f(N)=\frac{1-e^{-N}}{1+e^{-N}}$$

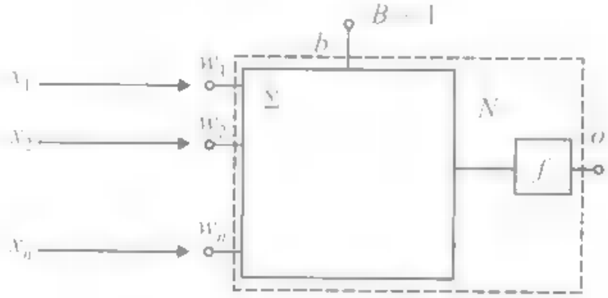


Fig 3. The perceptron

To solve a problem requires two steps : a training phase and a testing phase. During the training phase, a set of inputs are fed to the neural unit and the outputs they should produce are also known, and these are called targets. For example, for simulating an AND gate an input of [1, 0] should produce a target of [0] and an input of [1, 1] should produce a target of [1]. The weights are not known, so initial estimates are assumed (often random values or all zeroes). The actual output O produced can be calculated from Eq. (3) and Eq. (4) above. If the output does not match the target then an error is produced and this error is used to modify the weights in such a way that subsequent errors are reduced. This constitutes an iteration and is called an epoch. In the next iteration the inputs are again fed to the unit and the new weights are used to calculate the error. This process is repeated iteratively until the errors are all reduced to zero or some pre-defined small value. The unit is said to have converged and the final weights are called the balanced weights. The balanced weights provide a representation of the problem pattern since for all inputs these weights produce the correct outputs.

During the *testing* phase, an unknown set of inputs are fed to the neural unit and the balanced weights are then used to calculate the correct outputs. The power and flexibility of neural units lie in the fact that the test inputs need not be exactly identical with any of the training set inputs but only similar, for the perceptron to produce the correct decision. This property is frequently used to solve problem like pattern recognition and character recognition, where training is done using a separate set of characters and testing is done on another set of similar characters e.g. produced using a different font.

In most real-world problems instead of using a single perceptron, we use a network of connected neural units since we want multiple outputs at the same time. Such networks often have multiple layers of neural units between the input and output layers, in which case it is called multi-layered perceptrons (MLP) and the in-between layers are called hidden layers. See Fig. 4.

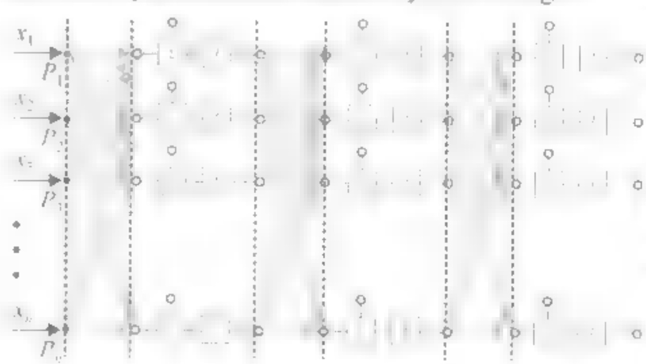


Fig. 4. A neural network

In MLP computations multiple errors are produced at the output corresponding to each neural unit, so a cumulative error called the Mean Square Error (MSE) is used for updating the weights, as depicted below, where *ei* is the error produced at the *i*-th output unit and there are *m* such units at the output

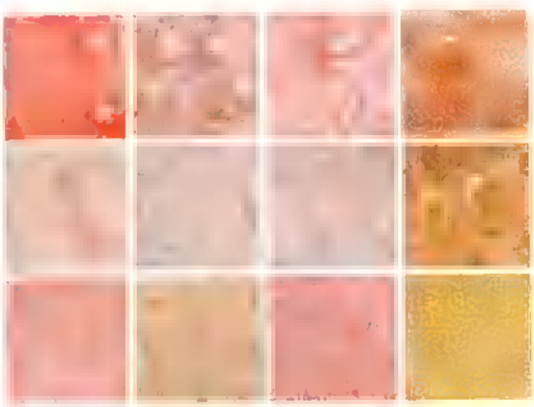
$$MSE=\frac{1}{m}\sum_{i=1}^{m} e_i^2 \qquad (5)$$

4. Experimentations and Results

4.1 Dataset

Skin texture images downloaded from Dermnet picture collection (http://www.dermnet.com/) are used in the experimentations. The dataset consists of a total of 180 images divided into three disease classes: Acne (Class-A), Ichthyosis (Class- I) and Keratosis (Class-K) with 60 images per class. Each image is 128 by 128 pixels in dimension and in GIF file format. A total of 90 images are used as the Training set (T) and the remaining 90 images as the Testing set (S). The images are arranged in the order A, I, K i.e. the first subset of 30 images of training (or testing) set belongs to Class-A, the next subset to Class-I and the last subset to Class-K. Sample images of classes A, I, K are shown in Figure 5.

For computing recognition rates, features are first considered individually, then in two-dimensional (2-D) feature space and finally in three-dimensional (3-D) feature spaces, involving multiple GLCM features simultaneously. Comparisons between training and testing sets are done using multi-layer perceptrons. At each stage the best results are tabulated and the corresponding discrimination plots are reproduced. The legends used in this work are listed in Table 1. Here X denotes a class name which can be either A or I or K.



(a)

(b)

(c)

Fig. 5. Samples of medical images belonging to three skin condition classes : (a) A (b) I © K

Table 1 : Legends

TXC	Training set, Class-X, GLCM Contrast
TXH	Training set, Class-X, GLCM Homogeneity
TXM	Training set, Class-X, GLCM Mean
TXV	Training set, Class-X, GLCM Variance
TXN	Training set, Class-X, GLCM Energy
SXC	Testing set, Class-X, GLCM Contrast
SXH	Testing set, Class-X, GLCM Homogeneity
SXM	Testing set, Class-X, GLCM Mean
SXV	Testing set, Class-X, GLCM Variance
SXN	Testing set, Class-X, GLCM Energy
X	Class name, either A or I or K

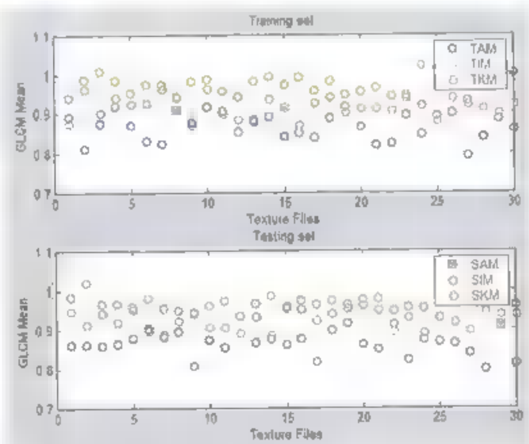
4.2 Individual Features

Values of individual GLCM features C, H, M, N, V defined in Eq. (2) for training and testing images for each of the three classes are computed. Test images are compared to training clusters using NN classifiers. Accuracy results are summarized in Table 2. The first column depicts the feature used, the second column shows the neural network configuration (NNC) viz. 1-10-3 indicates 1 input unit (for the individual feature), 10 units in the hidden layer and 3 units in the output layer (corresponding to the 3 classes to be distinguished). The third, fourth and fifth columns indicate the percentage recognition accuracies for the three classes, the sixth column provides the overall accuracy for the three classes and the last column indicates the best Mean Square Error (MSE) obtained during the training phase of the NNs. In all cases the NN classifiers were run for 50000 epochs. Feature values were appropriately scaled to lie within the range 0 to 1 before being fed to the classifier.

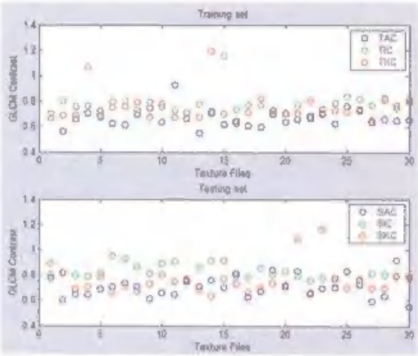
Table 2 : Accuracy results for single features

F	NNC	A	I	K	O	MSE
C	1-10-3	40	90	36.6	55.5	0.16
H	1-10-3	23.3	66.6	40	43.3	0.17
M	1-10-3	86.6	93.3	46.6	75.5	0.10
N	1-10-3	53.3	53.3	30	45.5	0.17
V	1-10-3	43.3	0	40	27.8	0.20
Avg		49.3	60.6	38.6	49.5	

From Table 2 it is observed, that best results are produced by M (75.5%) and C (55.5%). Corresponding plots depicting the variation of these feature values for the three classes over the training and testing datasets are shown below.



(a)



(b)

Fig. 6. Feature plots for (a)TAM, TIM, TKM, SAM, SIM, SKM (b) TAC, TIC, TKC, SAC, SIC, SKC

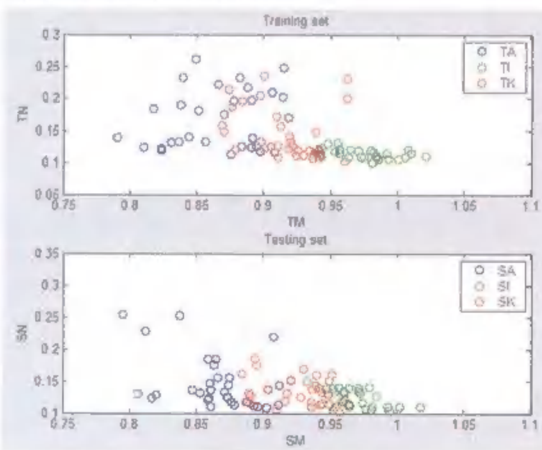
4.3 Joint Features in 2-D Feature Space

To improve upon the results obtained using individual features, joint features are next considered in two-dimensional feature spaces i.e. C-H, C-M, C-N, C-V, H-M, H-N, H-V, M-N, M-V, N-V. Accuracy results are summarized in Table 3. In all cases the NN classifiers were run for 50000 epochs. Feature values were appropriately scaled to lie within the range 0 to 1.

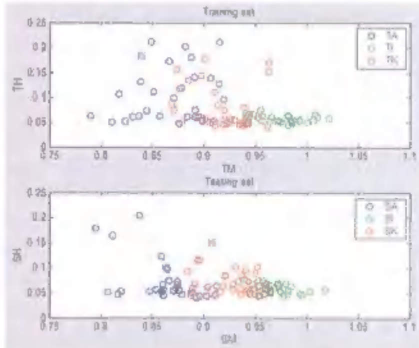
Table 3 : Accuracy results for joint 2D features

F	NNC	A	I	K	O	MSE
C-H	2-100-3	63.3	73.3	33.3	56.6	0.09
C-M	2-100-3	76.6	50	53.3	60	0.07
C-V	2-100-3	43.3	56.6	46.6	48.9	0.10
C-N	2-100-3	66.6	50	43.3	53.3	0.09
H-M	2-100-3	76.6	93.3	63.3	77.8	0.05
H-N	2-100-3	20	36.6	43.3	33.3	0.08
H-V	2-100-3	36.6	30	40	35.5	0.13
M-N	2-100-3	83.3	93.3	63.3	80	0.06
M-V	2-100-3	73.3	40	63.3	58.9	0.06
N-V	2-100-3	43.3	43.3	40	42.2	0.12
Avg		58.3	56.6	48.9	54.6	

From Table 3 it is observed that best results are produced by M-N (80%) and H-M (77.8%). Corresponding plots depicting the variation of these feature values for the three classes over the training and testing datasets are shown below.



(a)



(b)

Fig. 7. Feature plots for (a) TM vs. TN, SM vs. SN (b) TM vs. TH, SM vs. SH

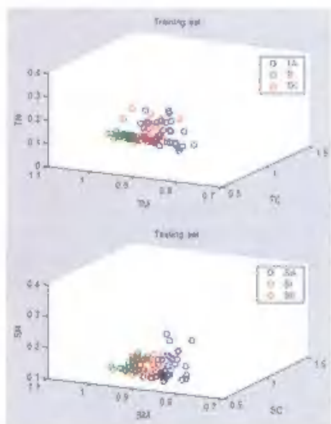
4.4 Joint Features in 3-D Feature Space

To improve upon the results obtained using individual features, joint features are next considered in three-dimensional feature spaces i.e. C-H-M, C-H-V, C-H-N, C-M-V, C-M-N, C-N-V, H-M-V, H-M-N, H-N-V, M-N-V. Accuracy results are summarized in Table 4. In all cases the NN classifiers were run for 50000 epochs. Feature values were appropriately scaled to lie within the range 0 to 1.

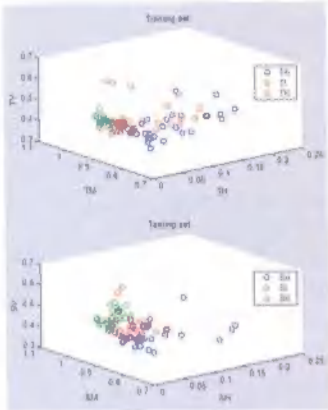
Table 4 : Accuracy results for joint 3D Features

F	NNC	A	I	K	O	MSE
C-H-M	3-150-3	73.3	86.6	63.3	74.4	0.04
C-H-M	3-150-3	56.6	30	36.6	41.1	0.11
C-H-M	3-150-3	53.3	30	66.6	50	0.06
C-H-M	3-150-3	66.6	26.6	40	44.4	0.07
C-H-M	3-150-3	86.6	93.3	66.6	82.2	0.04
C-H-M	3-150-3	53.3	50	46.6	50	0.09
C-H-M	3-150-3	83.3	80	63.3	75.5	0.04
C-H-M	3-150-3	76.6	90	53.3	73.3	0.05
C-H-M	3-150-3	60	33.3	53.3	48.9	0.08
C-H-M	3-150-3	93.3	63.3	60	72.2	0.04
C-H-M		70.3	58.3	54.9	61.2	

From Table 4 it is observed that best results are produced by C-M-N (82.2%) and H-M-V (75.5%). Corresponding plots depicting the variation of these feature values for the three classes over the training and testing datasets are shown below.



(a)



(b)

Fig. 8. Feature plots for (a) TC vs.TM vs. TN, SC vs. SM vs. SN (b) TH vs. TM vs. TV, SH vs. SM vs. SV

5. Analysis

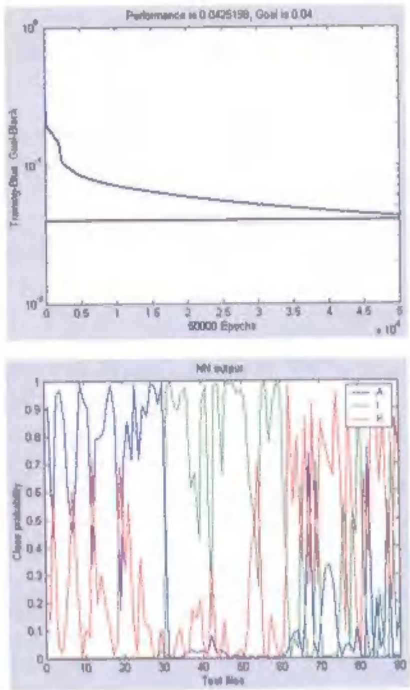
Automated discrimination between three skin texture classes was done using a variety of approaches to find the optimum results. Out of five GLCM based features considered individually, M produced the best recognition rate of 75.5%. Among joint 2-D feature spaces M-N produced the best result of 80%. Joint 3-D feature spaces were seen to improve on the accuracy rates to 82.2% using C-M-N. Best results are summarized below.

Table 5 : Best performance results

	Individual	Joint 2D	Joint 3D
F	M	M-N	C-M-N
%	75.5	80.0	82.2

Out of the disease classes, I was the best recognized using single features (60.6%), while A was the best recognized using 2-D features (58.3%) and 3-D features (70.3%).

The best recognition result, by using a combination of Contrast, Mean, Energy features, was obtained by using a neural network having a configuration of 3-150-3 i.e. 3 input units, 150 units in the hidden layer and 3 output units. The three feature vectors C, M, N of each training sample, were fed to the three inputs of the neural net and it was trained in this manner by a total of 90 samples, 30 per class. The perceptron took 50000 epochs to converge to an MSE value of 0.04. The network convergence and output plots are shown below. The output plot depicts a 86.6% accuracy for recognizing disease A, 93.3% for B and 66.6% for C, each class being represented by 30 test samples.



(a)

(b)

Fig. 9. NN convergence and output plots for the C-M-N feature vector

To put the above results in perspective with the state-of-the-art, the best results reported in [Shyu, 1999] for identifying disease classes from 302 lung section images involving texture features homogeneity, contrast, correlation and cluster, in addition to other features like grey-level histogram, is 76.3%. Accuracy for classification of 800 endoscopic images in [Xia, 2005] using a fusion of color, texture and shape features ranges from 77% to 90% but only about 25% involving texture features alone. Accuracy results reported in [Alabbadi, 2008] tested on 300 skin texture images is 96% but uses 9 color features in addition to 4 texture features, entropy, energy, contrast, homogeneity.

6. Conclusions and Future Scopes

This paper proposes an automated system for recognizing disease conditions of human skin by analyzing skin texture images using texture recognition techniques. Skin disease conditions differ in appearance in a way which cannot be modeled appropriately by specific colors and can best be identified using statistical variation of texture. Such automated medical diagnosis systems can prove extremely useful where there might be a dearth of good medical professionals. On one hand this would be useful for dermatologists to reduce diagnostic errors, while on the other it can serve as the initial test bed for patients before seeking expert advice.

The study reveals that performance improved when joint features were considered as compared to individual features. A salient feature of this approach is the low-complexity data modeling scheme whereby a small number of scalar values are used to represent image content, instead of multi-dimensional vectors like histograms. This makes the system low on computational overheads, and makes it suitable for use in remote and rural sectors, where computational resources can be scarce. Low resources also imply low cost involvements.

The accuracy of the current system is comparable to those reported in contemporary works. Most of the other works have dealt with 24-bit images and have utilized color based features in addition to texture based features. In comparison the current work has used 8-bit images and only texture based features. It is expected that accuracy results can be improved upon by using: (1) Color features along with texture, by employing GLCMs on individual R, G, B color channels of 24-bit images (2) Normalization of the brightness and contrast of the images by pre-processing, involving histogram equalization, before calculation of features.

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